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INTERNATIONAL GEOLOGICAL CONGRESS

Twenty-fourth session

CANADA-1972

FIELD EXCURSION A31 - C31

GEOLOGY AND MINERAL DEPOSITS OF THE FLIN FLON, LYNN LAKE AND THOMPSON AREAS, MANITOBA, AND THE CHURCHILL-SUPERIOR FRONT OF THE WESTERN PRECAMBRIAN SHIELD

GUIDEBOOK

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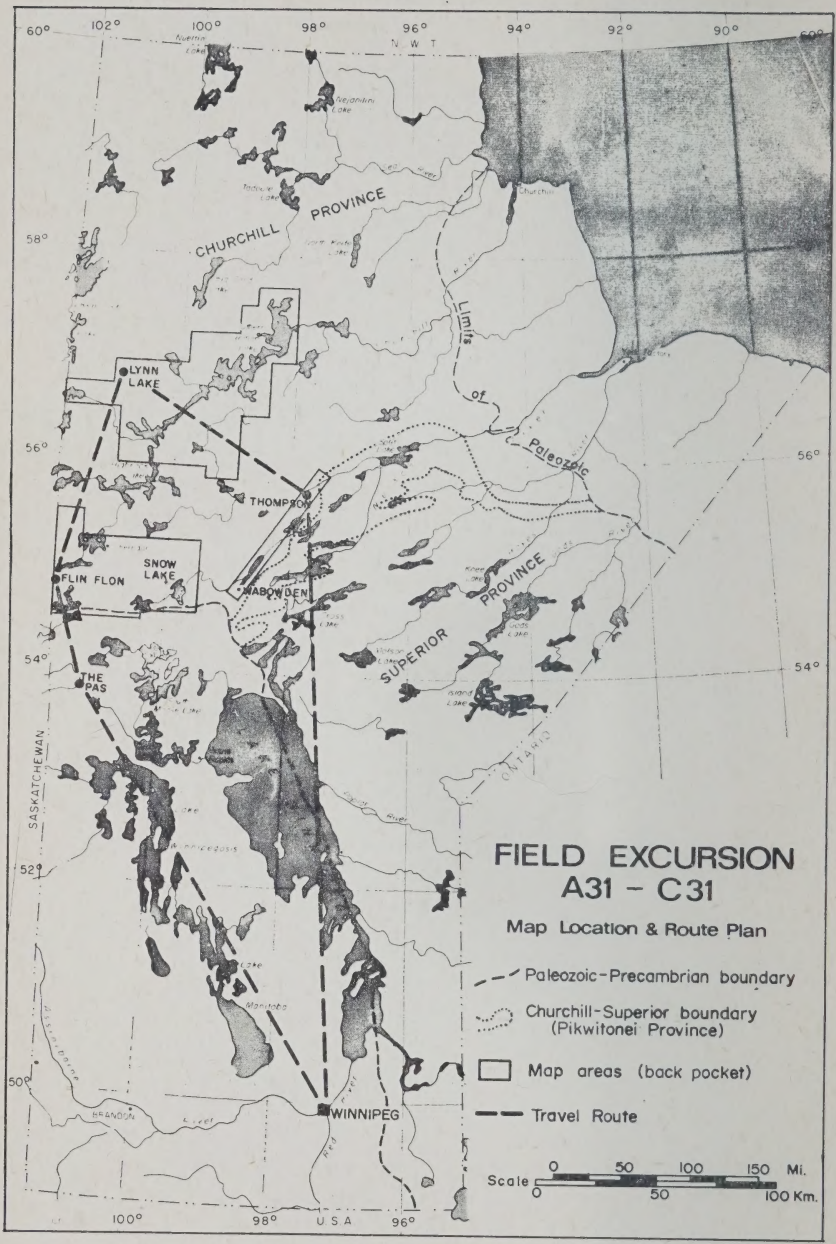
FIELD EXCURSION
A31 – C31
Map Location & Route Plan
Paleozoic-Precambrian boundary
Churchill-Superior boundary (Pikwitonei Province)
Map areas (back pocket)
Travel Route
Scale 0 50 100 150 Mi.
0 50 100 Km.
CHURCHILL PROVINCE
SUPERIOR PROVINCE
Limits of Paleozoic
LYNN LAKE
FLIN FLON
SNOW LAKE
THOMPSON
NABOWDEN
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Excursions A31 and C31

GEOLOGY AND MINERAL DEPOSITS OF THE FLIN FLON, LYNN LAKE AND THOMPSON AREAS, MANITOBA, AND THE CHURCHILL-SUPERIOR FRONT OF THE WESTERN PRECAMBRIAN SHIELD

C. J. A. COATS
Falconbridge Nickel Mines, Ltd., Winnipeg, Manitoba

T. T. QUIRKE, Jr.
The International Nickel Company of Canada Ltd., Thompson, Manitoba

C. K. BELL
Geological Survey of Canada, Department of Energy, Mines and Resources, Ottawa, Ontario

D. A. CRANSTONE
Mineral Resources Branch, Department of Energy, Mines and Resources, Ottawa, Ontario

F. H. A. CAMPBELL
Mines Branch, Manitoba Department of Mines, Resources and Environmental Management, Winnipeg, Manitoba

Guidebook Editor
D. J. GLASS
Canadian Export Gas & Oil Ltd.,
Calgary

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CONTRIBUTING AUTHORS

P. L. Martin: Hudson Bay Mining & Smelting Company Ltd., Flin Flon, Man.

D. P. Price: Hudson Bay Mining & Smelting Company Ltd., Flin Flon, Man.

G. D. Ruttan: Sherritt Gordon Mines Ltd., Lynn Lake, Man.

A. L. deCarle: Sherritt Gordon Mines Ltd., Lynn Lake, Man.

R. T. Worsfeld: International Nickel Company of Canada Ltd., Thompson, Man.

P. W. Green: Falconbridge Nickel Mines Ltd., Manibridge, Man.

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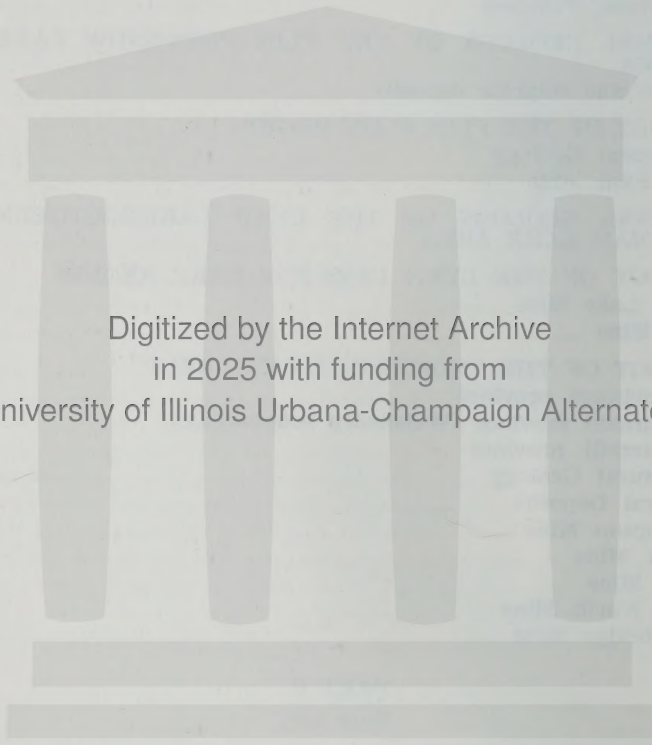

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PART I

Introduction

The excursion examines the three principal base metal producing regions of Manitoba, herein designated as the Flin Flon area, the Lynn Lake area and the Thompson nickel belt (Figure 1).

The first leg of the trip is to Flin Flon, where copper-zinc sulphide mineralization was discovered in 1914. In this area, well exposed rocks of low metamorphic grade offer an excellent example of the volcanic, sedimentary and related intrusive rocks which typify a Precambrian greenstone belt. The visit will include the Flin Flon mine, and one of the few remaining accessible levels from which production was initiated in 1930.

The Lynn Lake area is situated 145 miles (232 km) north of Flin Flon. It will be the site of the second phase of the field trip. Copper-nickel mineralization was first recognized at Lynn Lake in 1941 and initial production began in 1953. The Fox Lake deposit of copper-zinc sulphides, lying 27 miles (43 km) southwest of Lynn Lake, was discovered in 1961. Both these deposits and the geology at various points along the road between them will be examined.

The city of Thompson, which lies 145 miles (232 km) southeast of Lynn Lake, will be the base for the examination of the geology and ore deposits of the Thompson nickel belt. Nickel production at Thompson began in 1960, and has increased considerably since that time. Time will allow for prolonged stops at the Thompson, Pipe and Manibridge nickel deposits, and for the study of the geology along a 100 mile (160 km) length of the belt from Moak Lake in the north, to Manibridge in the south.

Map areas outlined on Figure 1 are the Snow Lake-Flin Flon-Sherridon Area (Map 1), the Lynn Lake-Southern Indian Lake Area (Map 2) and the Thompson nickel belt (Map 3). These geological maps together with the geological map of Manitoba (Map 4), are included in the pocket of the folder containing this guidebook.

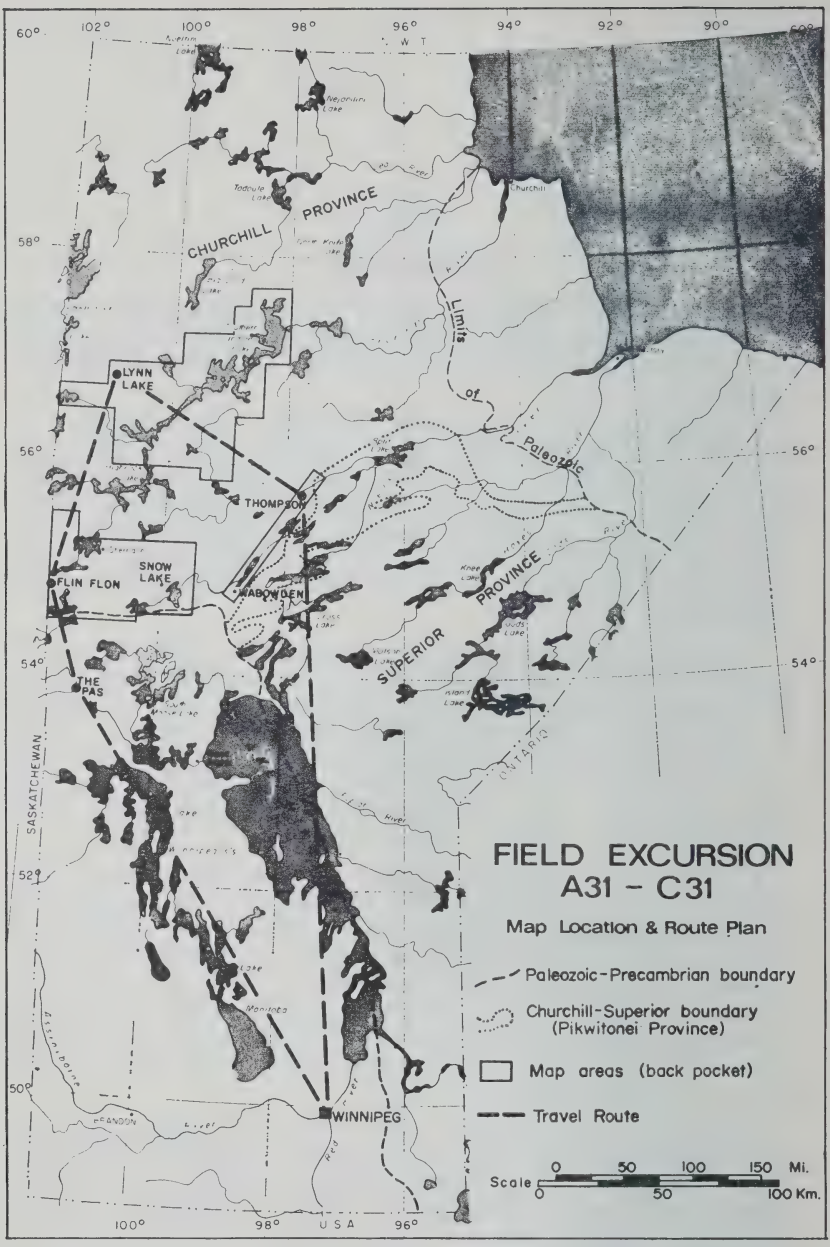

Fig. 1: Field Excursion A31-C31. Map location and route plan.

Physiography

A wide, peneplaned, Precambrian shield underlies three-fifths of the 250,000 square miles (650,000 sq. km) that comprise the Province of Manitoba. The exposed shield extends from northwest to southeast and separates the Paleozoic limestones and dolomites and Pleistocene marine deposits of the Hudson Bay Lowland from the Paleozoic and younger sedimentary rocks of the Great Plains Basin of western Canada (Figure 1). In the vicinity of Lake Winnipeg, both the flat-lying Paleozoic sediments and the Precambrian terrane are covered, to a depth of about 65 feet (20 m) by the Pleistocene varved clays of glacial Lake Agassiz. Areas underlain by flat-lying Paleozoic rocks and those that are covered by glacial moraine, and glacio-fluvial, marine and lacustrine deposits are sometimes low-lying and swampy. In these regions, outcrops are rare and generally restricted to river beds and lake shores. The Thompson nickel belt is an example of a clay-covered shield topography. Elsewhere, the Precambrian shield is characterized by elongate, glacially polished, outcrop ridges that seldom exceed 100 feet (30 m) in relief. These 'whale-back' hills are separated by innumerable depressions containing lakes and swamps that are connected by short, swiftly-flowing streams and rivers. Both the Flin Flon and Lynn Lake areas are typical examples of such terrain. North of lattitude 54°00′N, areas of permafrost remain beneath the extensive deposits of peat that have developed in the poorly drained areas. Drainage in the Precambrian region of the field trip is to the northeast, along the Churchill and Nelson River systems and into Hudson Bay.

Sources of Information

The entire Precambrian Shield in Manitoba has now been mapped, by the Geological Survey of Canada, at a reconnaissance scale of 1:253,440. Those areas showing greatest economic mineral potential, and geology that is critical to the regional interpretation, have been, and are still, being mapped by the Mines Branch of the Manitoba Department of Mines, Resources and Environmental Management at a scale of 1:63,360. Parts of Manitoba, such as the Flin Flon-Snow Lake area, have been previously mapped by the Geological Survey of Canada at this scale, or in more detail. Vertical aerial photographs, at various scales, are available for the entire

province. The results of an aeromagnetic survey have been published at scales of 1:63,360 and 1:253,440. These maps cover all but the southwest corner of Manitoba. Bouguer gravity anomaly maps of the entire province have been published at scales of 1:2,534,400 and 1:5,000,000. The boundary area between the Superior and Churchill provinces of the Precambrian shield, and including the 'Thompson nickel belt', has been surveyed by airborne AFMAG. This is an inductive electromagnetic method that relies on the natural electromagnetic fields in the ELF (Extremely Low Frequency) band (Collett and Bell, 1971). Publications resulting from these various surveys are available from either the Geological Survey of Canada, Department of Energy, Mines and Resources, Ottawa, Ontario, or from the Manitoba Department of Mines, Resources and Environmental Management, Winnipeg, Manitoba.

Mineral exploration organizations have mapped and prospected certain areas of economic interest in considerable detail. These surface examinations have been followed by surveys using every conceivable, airborne and ground, geophysical and geochemical technique that has been available. Diamond drilling of some of the anomalous areas has resulted in the discovery of ore deposits. Details of these endeavours appear in the scientific and technical literature.

Aspects of the regional geology of Manitoba are reviewed in Davies, et al. (1962), Douglas (1970), and Turnock (1971). The reader is also referred to the Geological Map of Manitoba (Manitoba Mines Branch, Map 65-1), the Geological Map of Canada, and the Tectonic Map of Canada (Geological Survey of Canada, Maps 1250A, 1251A).

Geology

The Precambrian shield in Manitoba is comprised of parts of the Superior, Pikwitonei and Churchill provinces. The terms Superior province and Churchill province have been used at different times, with geologic, structural, tectonic and/or geochronological connotations. They are considered here in the broadest possible geological sense, and for descriptive convenience they are supplemented by the addition of subprovinces that denote distinct geological terranes.

The Superior-Churchill provinces boundary in central Manitoba is unlike other shield boundaries in that it is marked by inliers of ancient, partially retrograded, granulite facies and amphibolite facies gneisses (Figure 2). These high-grade

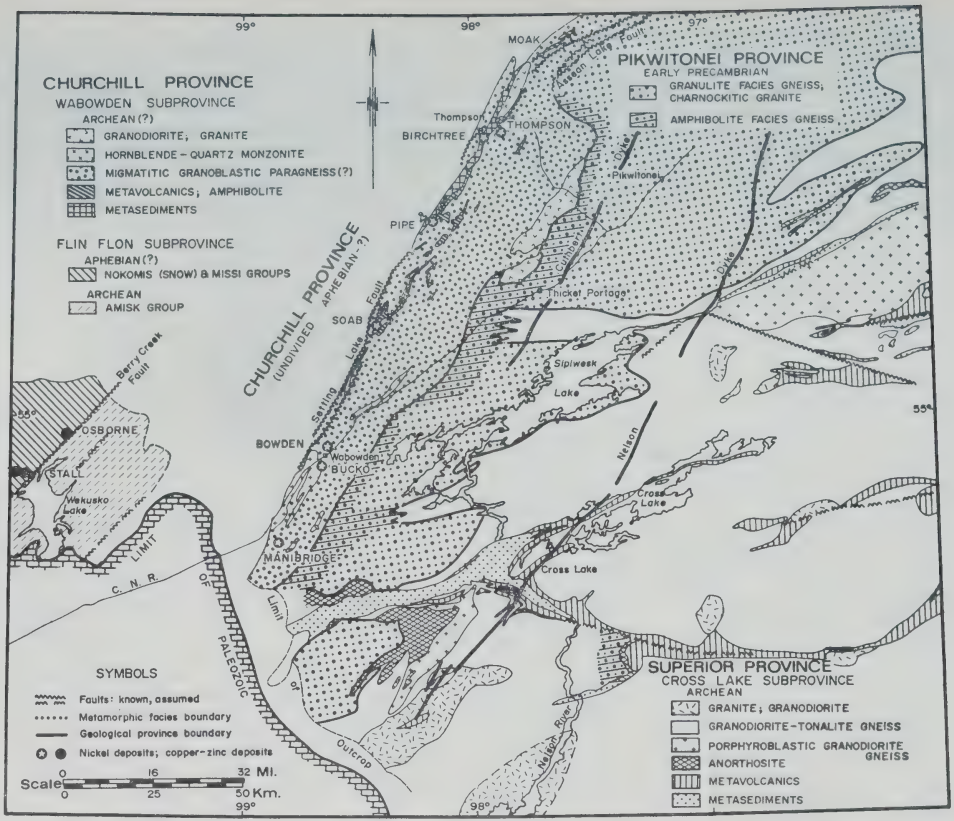

Fig. 2: Regional geology of the Churchill-Superior boundary and location of the Pikwitonei province.

metamorphic rocks are the remnants of an early Precambrian (cata-Archean) craton. These rocks have been assigned to a separate crustal block that has been named the Pikwitonei province (Bell, 1971c). The area of Superior province rocks lying immediately southeast of the Pikwitonei province was named the Cross Lake subprovince by Stockwell (1964). To date, two subprovinces have been proposed for parts of the Churchill province. The Wabowden subprovince is defined to include the rocks within the 'Thompson nickel belt' (Map 3). The Flin Flon subprovince includes some of the copper, lead, and zinc-bearing rocks of the Flin Flon-Snow Lake area. The present conception of these subprovinces may change in the future. Although the trend in the literature is toward the subdivision of provinces of the Canadian shield into discrete belts, blocks, or subprovinces, in this paper the Lynn Lake-Southern Indian Lake area is not defined as a subprovince nor is the vast area of Churchill province gneisses (Kisseynew-type) that were derived from rocks correlative with some of the units found in the Lynn Lake-Southern Indian Lake area and in Flin Flon subprovinces. The geology of the Superior, Churchill and Pikwitonei provinces is briefly outlined. This is followed by detailed descriptions of the geology of each of the regions that will be visited on the field trip.

Superior Province

Southeast of the boundary area, the Superior province is characterized by an Archean terrane in which narrow unmetasomatized, sedimentary-greenstone belts are preserved as conjugate systems of east-northeast-, and east-trending synclinoriums or synforms. These 'keels' of supracrustal rock sit in a 'sea' of synorogenic gneisses, anatexites, and local granitic plutons. These Archean rocks were included in the *Cross Lake subprovince* of the Superior province because of differences in their regional tectonic fabric, and because of anomalous K-Ar dates, younger than those that characterize the rest of the Superior province to the south (Stockwell, 1964). A wide zone of predominantly plutonic rocks with remnant inliers of supracrustal material that lies south of Cross Lake subprovince has been named the "Cat Lake belt" by Stockwell (Wanless, et al., 1968). To the south of the Cat Lake belt, identical plutonic and/or gneissic terranes separate three additional Archean, sedimentary-volcanic complexes. These southern zones of supracrustal rock also sweep easterly across the Superior province and they have been named the "Uchi", "Keewatin" and "Abitibi" belts (Goodwin, 1968). From the Churchill-Superior boundary, in the northwest, to

the Superior-Grenville front in the south, there is a progressive increase, across the Superior province, in the areal distribution of supracrustal rocks within each greenstone belt. This is accompanied by an increase in the proportion of acidic volcanic rocks and round to oval, granitic stocks. The intrusion of these intrasynformal plutons has altered the regional fabric of the greenstone belts but the typical Archean, east-trending fold geometry still prevails. This indicates that stress directions remained constant across the Superior province during an entire tectonic event that has been named the "Kenoran orogeny" by Stockwell (1961). The changes, from northwest to southeast, in the volume, configuration and lithology of the supracrustal rocks that form the synclinoria is suggestive of deeper erosion across the north half of the Superior province, with younger (stratigraphically higher) Archean rocks exposed in the Abitibi and Keewatin belts, and stratigraphically older units in the boundary area of Manitoba.

This hypothesis is supported by the fact that Archean basal conglomerate of the Cross Lake Group unconformably overlies early Precambrian granodioritic gneiss at Cross Lake (Rousell, 1965). Elsewhere in the same region, other members of the Cross Lake Group lie with large angular discordance on basement gneisses (Bell, 1971c). In addition, on a regional scale, synforms of metasomatic gneisses derived from Archean supracrustal rocks, including members of the Cross Lake Group, sweep from east to west along the boundary zone and transect Pikwitonei province granulites at high angles in a number of places (Figure 2). Consequently, it has been concluded that the 'type' Archean supracrustal members of the Cross Lake Group were deposited on an ancient continental surface that consisted, at least locally, of high-grade gneisses and granodioritic plutons. All rocks that underlie the Cross Lake Group have been included in the Pikwitonei province.

Therefore, by inference, the Cross Lake Group basal conglomerate is considered the oldest 'type' Archean formation so far identified on the Canadian shield. It is overlain by an intercalated complex of clastic sediments (conglomerate, greywacke, arkose, argillite, slate, protoquartzite, minor chert and iron-formation, and derived schists and gneisses), volcanic rocks (olivine basalt, tholeiitic, calc-alkalic and quartz basalt, and the metamorphic greenstone and amphibolite equivalents; andesitic, dacitic, and rare rhyolitic flows and pyroclastics and related, metasomatic quartzeye schists and gneisses). Widely dispersed mafic to ultramafic bodies

intrude the metavolcanic-metasedimentary sequence. Stratiform sequences of the same rock-types make up the other sedimentary-volcanic belts in the south half of the Superior province. Archean units as old as the Cross Lake Group have not yet been identified as such in these stratigraphically younger belts because the basement members would presumably be deeply buried. However, in a number of places within the Superior province, younger Archean sediments have been found lying unconformably on an older Archean terrane of either volcanic flows or sediments. While these unconformities have been considered local depositional features, they may indicate a major erosional period during the Archean. The rocks within the various Archean sedimentary-volcanic belts have still to be correlated on a regional scale. They are presently given local rock-stratigraphic names for descriptive purposes.

All of the Archean supracrustal groups have been folded at least once during the Kenoran orogeny. This deformation was accompanied, and/or followed, by extensive transverse and transcurrent faulting. Late Archean, and possibly some early Aphebian (Proterozoic) transverse faulting smeared many of the Cross Lake subprovince greenstone belts into their present elongate shapes. At this time the Archean terrane that makes up the Superior province became a stable craton.

The greenstone belts in the Cross Lake subprovince were initially prospected for gold. Since then, attention has been focussed on lithium- and beryllium-bearing pegmatites, and more recently on the ultramafic bodies for their nickel-bearing sulphide potential, and on the felsic volcanics for strata bound, syngenetic, base metal deposits. Some exploratory diamond drilling has been done on a deposit of vanadium-bearing titaniferous magnetite that occurs in a differentiated gabbro-anorthosite sill southeast of Cross Lake (Rose, 1967). Economic mineral deposits have not yet been reported in the Cross Lake subprovince.

Churchill Province

The geology of that part of the Churchill province lying within Manitoba can be summarized by constructing a hypothetical model of its evolution in relation to the Pikwitonei and Superior provinces to the southeast.

The oldest supracrustal rocks have been assigned to the Amisk Group in the Flin Flon-Snow Lake area and to the Wasekwan Group in the Lynn Lake-Fox Lake area. These

old greenstone complexes are characterized by volcanic-sedimentary sequences that have a relative abundance of felsic volcanic rocks and round to ovoid granitic stocks and batholiths. This lithology is comparable with that found in the thick Archean sequences that occur in the highly mineralized Abitibi belt that borders the south edge of the Superior province in Ontario and Quebec (Goodwin, 1968). Recent whole rock Rb-Sr isochrons in nearby parts of the Churchill province (Money, 1968; Coleman, 1970; and Sinha, 1970) suggest Archean ages for the greenstone belts, but Mukherjee, et al, (1971) have proposed that the Amisk Group volcanics are late Aphebian (Proterozoic). Subsequent Hudsonian (?) deformation has destroyed the details of the conjugate Archean fold patterns of the infolded belts, however, the overall eastern-trend of the belts is still apparent in the outcrop distribution, and in the distinct east-west regional aeromagnetic pattern that persists across the southeast portion of the Churchill province (Magnetic Anomaly Map of Canada, GSC 1255A). These aeromagnetic patterns are interpreted as the magnetic response from an exposed, and buried, Archean terrane. Accordingly, geology and geophysics support the existence of an Archean craton beneath at least parts of the southeast-half of the Churchill province. It is assumed that the craton was once part of a larger Archean craton whose remnant now makes up the Superior province.

Late in the Kenoran orogeny, the original Archean craton broke (in half) along a line that is now approximated by the north edge of the Pikwitonei province. The southern or Superior plate then tilted up and this uptilted north half created a high craton that became juxtaposed against what had become the lower, essentially downfaulted, Churchill craton. This tectonic block adjustment was followed by erosion and northerly transportation of sediments off the uplifted plate onto an Archean lowland that had become covered by an Aphebian (early Proterozoic) continental sea. Comparisons of lithological, aeromagnetic and Bouguer gravity data suggests that this initial deposition on the Churchill plate culminated in geosynclinal development north of the Superior plate. This entire episode may prove correlative with the orogeny that formed the Circum-Ungava geosyncline (Dimroth, et al, 1970) which extends from the east side of the Hudson Bay, around Ungava to the Labrador Trough. In its simplest manifestation, the southeastern half of the Churchill province may be considered as an Archean basement that is overlain by early Aphebian miogeosynclinal and

eugeosynclinal deposits that belong to the supergroup that underlies the Circum-Ungava geosyncline (Bell, 1971a). Synkinematic or postkinematic anatexis has granitized both the Archean basement and overlying Aphebian rocks to produce the complex "Kisseynew-type" gneissic terrane that now comprises much of the southeastern half of the Churchill province.

In the *Lynn Lake-Fox Lake area* (Figure 9), the older Wasekwan Group (intercalated conglomerate, quartzite, greywacke, iron-formation and slates; mafic and intermediate lavas and derived amphibolites, tuff, agglomerate, and volcanic breccia), and the "post Wasekwan Intrusives" (gabbro, norite, hornblendite, diorite, hornblende-biotite diorite, quartz diorite; hornblende-biotite grandiorite; and biotite and hornblende granite) are probably part of the Archean basement. These rocks are overlain unconformably (disconformably and non-conformably) by what is tentatively assumed to be Aphebian, Sickle Group basal conglomerate, minor pillow basalt and volcanic breccia and derived amphibolites, and arkose, quartzite, greywacke, and minor pebble conglomerate. "The Wasekwan-Sickle complex is bounded to the north by granitic rocks and gneisses of indeterminate age. To the southwest, the Wasekwan and Sickle rocks have been mapped as gradational into Kisseynew-type gneisses. There is no distinct boundary in the southeastern part of the complex." Campbell, et al, (1970, p. 33).

The most recent interpretation of the Flin Flon-Snow Lake *(Flin Flon subprovince)* geology (Figures 3, 4) has been presented by Bailes (1971). The evolution of the terminology for the local rock-stratigraphic units was previously reviewed by Harrison (1951), and by Davies, et al, (1962). The oldest rocks occur in a volcanic-sedimentary complex, and have been named the Amisk Group. These are typical, intermediate to high stratigraphic level, Archean assemblages of mafic to intermediate, massive and pillowed flows, and associated pyroclastics; dacitic to rhyolitic quartz porphyry stocks that may, in part, represent volcanic plugs; and intercalated quartzites, greywackes, siltstones and argillites that are locally tuffaceous. In some localities, these rocks have been metamorphosed to various staurolitic paragneisses and schists. Metasomatism has further altered the sedimentary units to garnetiferous quartz-plagioclase-biotite gneiss, and the intermediate to acidic pyroclastics to quartz-eye gneiss. Some of the local quartz-eye granite may be igneous and plutonic. The post-Amisk intrusives include the Cliff Lake granodiorite and

stocks of diorite, and gabbro with anorthositic and ultramafic phases. The Amisk Group supracrustal and intrusive units are overlain unconformably, and locally disconformably (?), by Missi Group sediments (greywacke, minor arkose and quartzite, and pebble beds that contain clasts of the Amisk and post-Amisk rocks) and in the area east of Wekusko Lake by Missi volcanics (andesite, minor basalts that may retain pillow structures, thin horizons of porphyritic rhyolite, layers and beds of agglomerate and volcanic breccia, and interlaminated feldspathic chert and greywacke) (Frarey, 1950). Difficulties have been encountered in distinguishing certain Missi sedimentary units from the Amisk sediments, and in deciding whether the Amisk-Missi unconformity is an Archean erosional feature, or the stratigraphic break between the Archean and Aphebian. The latter interpretation is tentatively adopted for this summary. Another local sequence of supracrustal rocks has been named the Nokomis Group. The rocks of this group are considered part of the Kisseynew-type gneiss complex and they are tentatively correlated with the Amisk sediments. The Nokomis Group consists of metamorphosed argillite and greywacke that occurs as granoblastic plagioclase-quartz-biotite-garnet gneiss with, or without staurolite, sillimanite, cordierite and graphite; and various amphibolitic and hornblende-plagioclase gneisses that are part metavolcanic and part metamorphosed calcareous sediments. The thick sequences of metamorphosed arkoses and quartzites that conformably (disconformably?) overlie the Nokomis Group have been named the Sherridon Group. These occur as thickly bedded, openly folded, quartz-plagioclase-orthoclase-biotite-hornblende gneisses that may be garnetiferous. There apparently was "a marked contrast in sedimentary environment and mode of deposition between the Nokomis and Sherridon sequences. The presence of turbidites in the Nokomis Group may be taken to imply a relatively deep water environment with an adjacent elevated land mass. The Sherridon Group of finely laminated quartzitic and arkosic sedimentary rocks is more characteristic of sedimentation in a shallow water and/or fluvial deltaic environment." Bailes (1971, p. 11), It is again tentatively assumed here that the Missi and Sherridon Groups are all part of the Aphebian supergroup that forms the Circum-Ungava geosyncline. This assumption is too general to explain some of the complicated stratigraphic relationships that obviously exist in the Flin Flon-Snow Lake area and that probably exist in the Lynn Lake-Southern Indian Lake area. Many of the structural and lithological anomalies may be explained by consider-

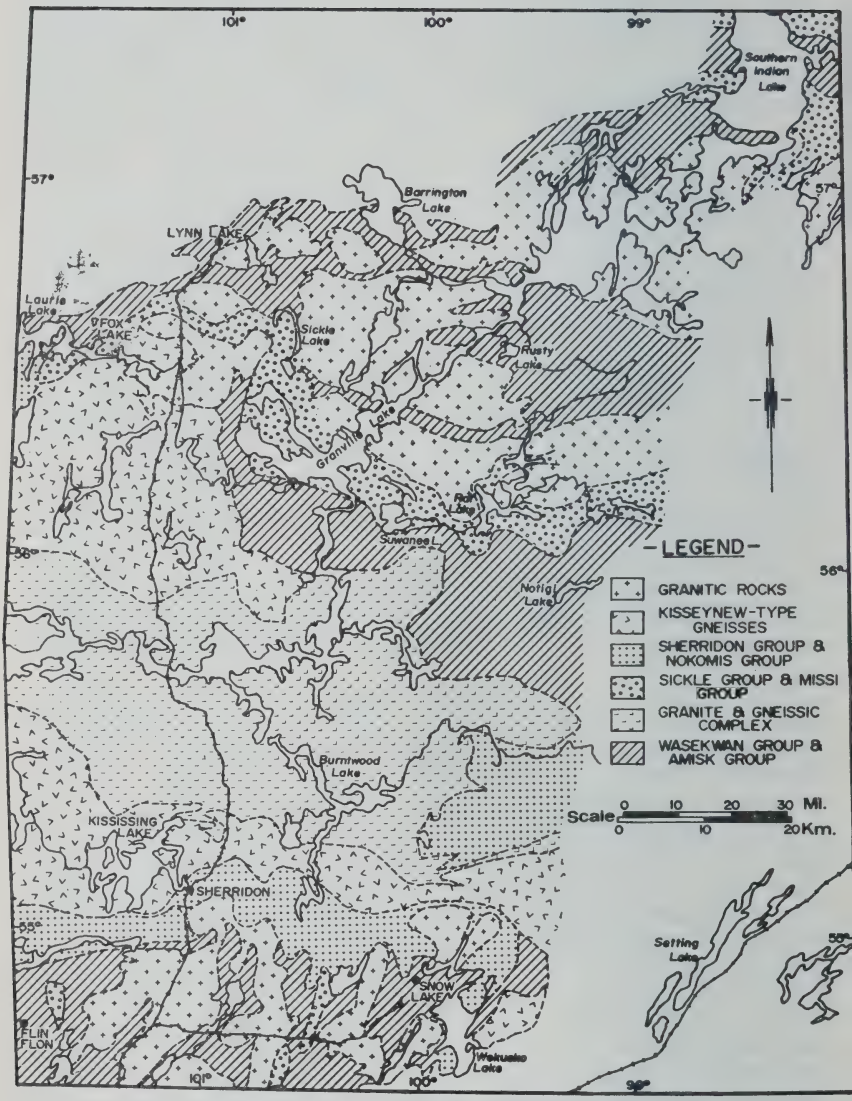

Fig. 3: Regional geology of the Flin Flon-Snow Lake-Lynn Lake area, Western Manitoba.

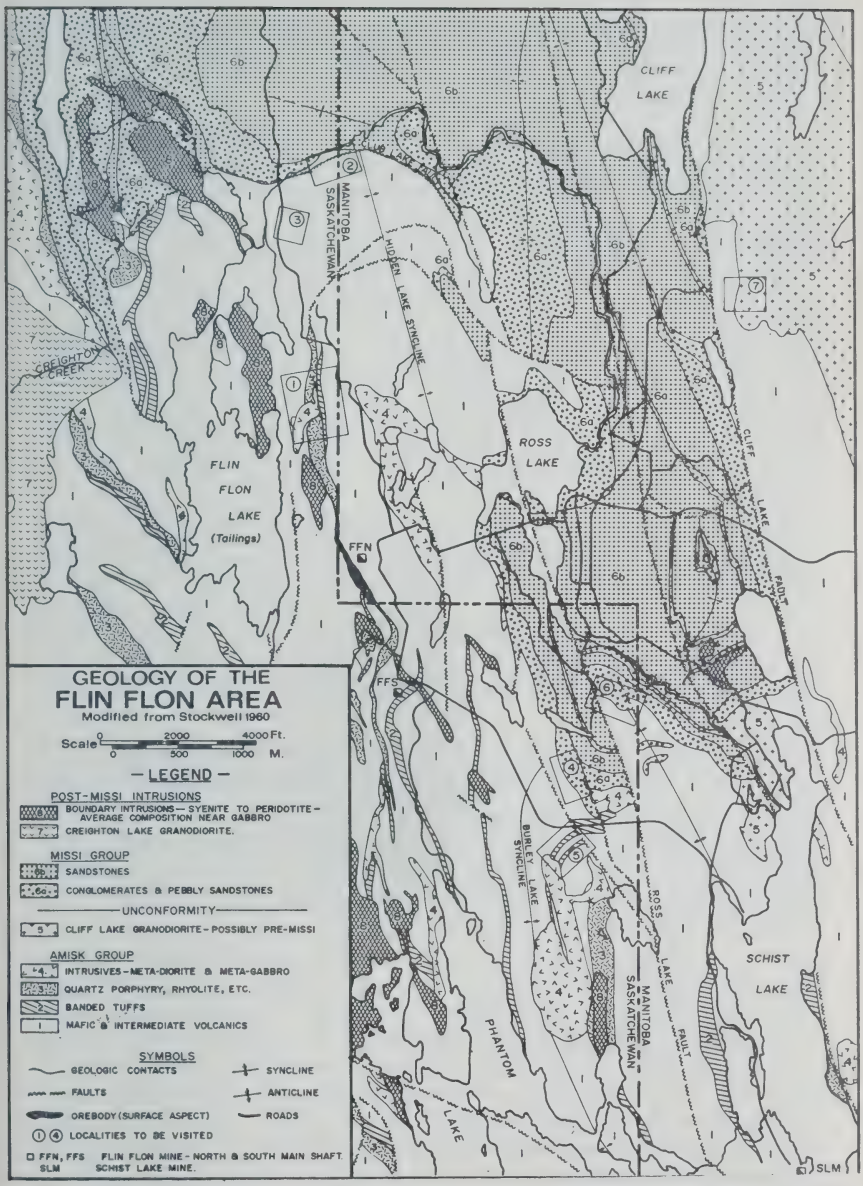

Fig. 4: Geology of the Flin Flon area, Manitoba-Saskatchewan.

ing that in the southeast portions of the Churchill province, Archean 'highlands' may have once been preserved and would have provided provenances for local sedimentation that was distinct from the main influx of detritus off the Archean (Superior) continent to the south.

Pervasive, regional, soda-, and potash-metasomatism, metamorphic differentiation, and localized anatexis followed the early Aphebian geosynclinal development and vast volumes of Aphebian, and unknown amounts of Archean rock were reconstituted and remobilized. The products of this Hudsonian metamorphic event are the ubiquitous, often garnetiferous granite, quartz monzonite and granodiorite gneisses and plutons, and the migmatitic and agmatitic paragneisses and granitoid gneisses that underlie much of the southeast half of the Churchill province and separate the Archean greenstone belts from one another. These complexly folded and 'domed' complexes are the contentious *Kisseynew gneisses* that are reviewed in detail by Harrison (1951) and briefly by Bailes (1971), (Figure 3).

The *Wabowden subprovince* encompasses the rocks of the 'Thompson nickel belt' (Figure 2). On the northwest, the subprovince is faulted against the undivided Kisseynew-type gneisses that underlie large regions in the southeast half of Churchill province. The southeastern boundary of Wabowden subprovince is, by definition, the southeastern margin of the Churchill province and it marks the limit of pervasive Hudsonian deformation.

Approximately eighty per cent of the Wabowden subprovince is underlain by a layered, granoblastic, migmatitic paragneiss. Quartzite, meta-arkose, conglomerate, marble, skarn and iron-formation, plagioclase-hornblende paragneiss, and metavolcanic rocks, related greenstones (probably including tuff) and amphibolite, all form mappable units within these paragneisses.

Some of these stratiform rocks have been intruded by elongate, lens-shaped granitic stocks. Bell (1971c) proposes that certain of these granitic bodies could have been formed by a process of "shear melting" at depth and that they are the byproducts of anatexis due to the transcurrent faulting that affected all the Thompson belt units. This faulting also produced zones of shearing, cataclasis, mylonitization and ultramylonitization that are up to hundreds of feet in width. Serpentinized ultramafic bodies occur within, or adjacent to, all the Thompson belt units.

It is impossible to assign a time-stratigraphic age to the Thompson belt rocks because, on the northwest, they are juxtaposed against the Kisseynew-type gneisses along the Setting Lake fault (Figure 2), and because their relationship to the early Precambrian Pikwitonei province gneisses that lie to the southeast, is unknown. The best indication of their time of formation was presented by Rance (1966) when he concluded that the Thompson belt rocks retained a Kenoran metamorphic fabric that had been transposed during the Hudsonian orogeny into Hudsonian tectonites. Alternatively, Cranstone proposes that at least some of the Thompson belt gneisses are the retrograded equivalents of the Pikwitonei province granulites. On the basis of lithology they compare locally with the 'type' Archean rocks of both the Cross Lake and Flin Flon subprovinces; but some units are also similar to the Aphebian sediments that occur in the Churchill province. The omnipresent Hudsonian K-Ar ages are apparently the product of updating during this thermal event. It is assumed, however, that the original supercrustal rocks within the Wabowden subprovince are older than the 2035 m.y. K-Ar date that was obtained on a pegmatite offshoot from the Ospwagan granite (Wanless, et al, 1967, p. 81). Consequently, the Thompson belt rocks could be either early Precambrian, Archean or early Aphebian.

If the Thompson belt rocks are Aphebian, they may be correlative with the supracrustal deposits of the Circum-Ungava geosyncline. This would allow comparisons of the Thompson belt nickeliferous serpentinites with the ultramafics that would then occur in the same geotectonic position: (1) east of Thompson in the 'Fox River complex' (Bell, 1966), (2) along the north shore of the Ungava Peninsula in the Cape Smith belt, and (3) in the Labrador Trough of central Ungava. Alternatively, if the Thompson belt rocks are Archean, they would lie unconformably on the Pikwitonei province basement gneisses. They would then represent the autochthonous remnants that remained after the once adjoining, Archean Flin Flon subprovince block was faulted to the southwest along the sinistral, transcurrent Setting Lake fault (Figure 2). However, if the units that make up the Wabowden subprovince were positioned by faulting, they would represent a horst of Archean basement which once adjoined the Archean continental plate that is assumed to underlie the Aphebian geosynclinal deposits of the Churchill province. It is also possible that the Thompson belt units are part of an Archean allochthon that slid northwest off the 'high Superior-Pikwi-

tonei craton' into the Aphebian sea. In this latter case, the Thompson belt rocks could possibly correlate with the upper members of the Cross Lake Group.

The geology in the Thompson belt is the end-product of a long history of shearing and mylonitization along a northeast-striking swarm of anastomosing faults. This faulting was preceded and/or accompanied by complex folding; regional metamorphism and metasomatism (including serpentinization); re-injection by tectonic transport of ultramafic bodies; intrusion of hornblende quartz-monozonite, granodiorite and granite stocks, pervasion by granite and pegmatite with the consequent development of migmatites and agmatites; contact metamorphism in association with the emplacement of these granitic rocks, and late remobilization and/or introduction of sulphides. Major faulting continued until the end of the Hudsonian orogeny. Protected by the stable Pikwitonei province craton on the southeast, and perhaps by the main Setting Lake fault on the northwest, the Thompson belt rocks of the Wabowden subprovince appear to have remained an enclave with an Aphebian history that was unique in the boundary area. Bell (1971c).

Pikwitonei Province

It is proposed that the oldest rocks so far discovered in the Canadian shield are the pyroxene granulite facies, or hypersthene-bearing, crystalline gneisses and charnockites, the retrograded, amphibolite facies derivatives, and possibly some amphibolite facies gneisses that make up the Pikwitonei province. As previously noted, these ancient rocks occur as inliers that are overlain unconformably by Archean, Superior province rocks. In the boundary area they are either faulted against, lie unconformably below, or are part of the early Precambrian (Aphebian?) Thompson belt rocks of the Churchill province. The distinct aeromagnetic pattern and the strong Bouguer gravity high ["Nelson River high" (Innes, 1960)], that reflect the hypersthene-bearing members of these gneisses, enables an extrapolation of the Pikwitonei province eastward, beneath the Paleozoic and Pleistocene deposits of the Hudson Bay Lowlands. East of 94°00′W, the rocks of the basement complex are interpreted to occur as a narrow, linear, infracrustal ridge of granulite facies rocks that are similar to those in the outcrop area to the west. These basement rocks are still assumed to lie unconformably beneath the Archean rocks of the Cross Lake subprovince, and they are either faulted against, or lie unconformably

below the metavolcanic-metasedimentary belt that includes the Fox River ultramafic stratiform complex (Scoates, 1969). The easternmost extremity of the Pikwitonei province is overlain unconformably by the undeformed Nowashe and Sutton Ridges Formations of Aphebian age (Bostock, 1971; Bell, 1971b).

The granulite facies members of the Pikwitonei province cannot be extended south, beyond the north end of Lake Winnipeg by geophysical methods. In this area, and to the south, the Archean Superior province rocks are interpreted to be in faulted (?) contact with Churchill province rocks that are of unknown age.

In the field, the majority of the Pikwitonei province granulite facies gneisses can be classified as variants of green diorite or enderbite, that, in most cases, show signs of retrograde metamorphism.

Retrogressively metamorphosed, amphibolite facies gneisses are everywhere interlaminated with the granulite facies units, and they also form a narrow zone along the northwestern edge of the province (Figure 2). These polymetamorphic gneisses are assumed to be retrograded equivalents of the granulites and therefore part of the Pikwitonei province. They are granoblastic, medium-, to coarse-grained to augen-textured rocks that range from leucocratic, plagioclase-quartz-(biotite)-gneisses; through intermediate, plagioclase-biotite-hornblende-quartz gneisses; to mafic, hornblende gneiss, amphibolite and metadiorite. These gneisses can be garnetiferous. They are all variously interlaminated to form a widespread, layered, black and white gneiss. A later addition of granitic material has produced a variety of agmatite that has separated the dark primary layers into blocks and boudins. The end product of this process is a coarse-grained, white, anatexite that has the composition of quartz-monzonite to granodiorite, and that contains inclusions of the original layered gneisses.

Regional Geology of the Flin Flon-Snow Lake Area

Although the first part of the excursion will be restricted to the immediate vicinity of Flin Flon and an examination of the outcrops of this classic area of the western Precambrian Shield, the following description must include the adjacent area of Snow Lake to preserve geological continuity with regard to the regional setting.

The Precambrian rocks of the Snow Lake-Flin Flon-Sherridon region (Map 1), comprise two broad easterly trending belts of rocks of differing lithology, degree of deformation and grade of metamorphism. These belts are referred to as the Flin Flon-Snow Lake greenstone belt (in the south) and the Kisseynew metasedimentary gneiss belt (in the north). The southern belt is composed of greenschist to lower almandine-amphibolite facies volcanic and sedimentary rocks. The northern belt comprises complexly deformed middle to upper almandine-amphibolite facies sedimentary gneisses and associated granitic rocks. Byers et al, (1965) refer to the contact of these belts as being gradational at the west end of the 'Kisseynew Front Lineament'. Bailes (1971) judges the two belts to be in fault contact from north of Flin Flon to a point east of File Lake. Further to the east, in the vicinity of Snow Lake, the two belts are gradational into one another across a zone of steep metamorphic gradients with little or no faulting.

*Geology**

The Flin Flon-Snow Lake greenstone belt of volcanic and sedimentary rocks outcrops over a distance of 150 miles (240 km), extending from 20 miles (32 km) east of Snow Lake to 30 miles (48 km) west of Flin Flon. The belt has an average exposed width of 30 miles (48 km) and is overlain by flat-lying Paleozoic sedimentary rocks along its southern margin.

The greenstone belt comprises four main sequences, from oldest to youngest: The Amisk Group; the Post-Amisk Intrusive Group; the Missi Group; and the Post-Missi Intrusive Group (Table 1). This sub-division closely follows that developed by Bruce (1918) during his early reconnaissance studies of the Amisk-Athapapuskow Lake district. He first established the terms 'Amisk' and 'Missi' for the volcanic and sedimentary groups respectively from their type localities at Amisk Lake and Missi Island in Amisk Lake, Saskatchewan. However, at this time, there is considerable uncertainty regarding the age relations of the intrusive rocks included here under the heading "Post-Amisk Intrusive Group". Detailed observations on this problem are outlined in a later section on the geology of the Flin Flon region.

The *Amisk Group* is composed of a thick sequence of volcanic strata ranging from basalt to rhyolite, with intercalated

*After Bailes (1971)

volcaniclastic sediments. The Amisk volcanism began with widespread extrusion of thick sequences of mafic flows (A1a). These flow rocks are commonly pillowed, indicating submarine extrusion. Unit A1b consists of mafic to intermediate pyroclastic rocks, which include agglomerate, tuff and ash deposits. The mafic lavas and pyroclastic rocks of unit A1 commonly have small, mafic, fine-grained, and probably comagmatic intrusions associated with them. These small intrusions have not been distinguished from the other rocks of unit A1 on Map 1.

Table 1

TABLE OF FORMATIONS
(After Bailes, 1971)

Flin Flon-Snow Lake Greenstone Belt

POST-MISSI INTRUSIVE GROUP

A8 Intrusive rocks of variable composition related to unit A7

A7 Granodiorite and quartz diorite, generally gneissic. Large portions represent metasomatically granitized material

..... INTRUSIVE CONTACT .....

MISSI GROUP

A6 Arkose, greywacke, quartzite. Basal conglomerate common

..... UNCONFORMITY .....

POST-AMISK INTRUSIVE GROUP

A5 Gabbro and diorite often with ultrabasic phases. Commonly differentiated. Includes rocks of several ages and diverse origins

A4 "Quartz-eye" granite

..... INTRUSIVE CONTACT .....

AMISK GROUP

A3 Argillite, greywacke, tuff. Turbidites common in eastern region

A2 Rhyolite, dacite, quartz porphyry. Includes acidic crystal tuff and siliceous, carbonate-rich tuff

A1 Mafic to intermediate volcanic rocks (a) pillowed varieties, and (b) fragmental varieties. Includes many small related intrusions.

As the Amisk volcanism progressed it became: (1) gradually more acidic, (2) increasingly localized to smaller centres of extrusion, and (3) more fragmental. The resulting acidic volcanic rocks of unit A2 are highly variable. They include dacitic and rhyolitic flow rocks, and their pyroclastic equiva-

lents; acidic tuff deposits of various types; and some tuffaceous, cherty and carbonate-rich sedimentary rocks. Certain intrusive quartz porphyries, which possibly represent feeders for the acidic extrusive material, have been included in unit A2.

Argillitic and tuffaceous sediments of unit A3 were probably derived by erosion of pyroclastic deposits. They occur at various levels throughout the volcanic sequence, but are commonly associated with the later acidic volcanic phases. The sedimentary rocks of unit A3 can be subdivided into two general categories: (i) volcaniclastic sediments consisting of thin beds of tuffaceous siltstones and greywackes; and (ii) turbidite-greywacke and siltstone sequences which form thicker and more widespread deposits than (i). The two categories of unit A3 have not been distinguished on the geological map.

The *Post-Amisk Intrusive Group* includes "quartz-eye" granite (A4) and mafic intrusive rocks (A5). These rock types generally show a close spatial relationship, and are possibly co-magmatic. The intrusions of unit A4 range in size from small irregular masses similar to those east of Wekusko Lake, to stocks, like the intrusion south of Elbow Lake, that are over 25 square miles (64 sq. km) in area. The large sill-like body of "quartz-eye" granite south of Snow Lake (Harrison, 1949) was mapped as a sedimentary rock by Russell (1957). It was subsequently classed as an acidic pyroclastic tuff by Williams (1966). On the basis of Williams' conclusions, the mass has been included with the acidic volcanic rocks of unit A2 on the compilation map. More recent mapping by N. Russell (1970, personal communication) indicates that this body is, at least in part, intrusive. The mafic intrusive rocks (A5) are of diverse origin and of different ages, all post-Amisk. Many of these intrusions contain ultramafic phases, and some of them are noticeably differentiated e.g. the Chisel Lake intrusion.

The Amisk Group and Post-Amisk Intrusive Group are unconformably overlain by a relatively clean, detrital sequence of arkose, greywacke, and quartzite, forming the *Missi Group*. Pebble or boulder conglomerate beds, with recognizable clasts of the Amisk and Post-Amisk Intrusive rocks, are located at, or near, the base of this unit. Crossbedding is a characteristic of the Missi rock. The contact of the Missi Group with the lower units is usually disconformable, although there is a local angular discordance.

The *Post-Missi Intrusive Group* includes large granitic bodies, often of batholitic dimension, that fall into two general categories: (1) unit A7; gneissic intrusive rocks of granodiorite composition that are generally conformable with the surounding units; and (2) unit A8; intrusive, generally nonfoliated, acid to basic rocks which intrude unit A7.

K-Ar dates of rocks from the Snow Lake-Flin Flon-Sherridon region range from 1610 to 1960 million years. On the basis of these dates, the main deformation and metamorphism of this region is considered to be Hudsonian. Two factors suggest, however, that the culmination of metamorphism and deformation in this region may have taken place at an earlier date, possibly during the Kenoran orogeny.

1) In the Snow Lake-Flin Flon-Sherridon region there is a dominant easterly trend in the foliation and/or layering of the Kisseynew gneisses, in the major tectonic units such as the Flin Flon-Snow Lake greenstone belt and the Kisseynew gneiss belt, and in the aeromagnetic patterns (Kornik and MacLaren, 1966). This is in accord with the Archean, Superior trends which are characteristically easterly. In contrast, the normal Churchill fabrics are generally considered to be northeasterly.

2) Rb-Sr whole rock dating by Coleman (1970) of rocks from the Hanson Lake area, 40 miles (64 km) west of Flin Flon gave a date of 2,521 million years for Amisk-type metavolcanic rocks, and a date of 2,446 million years for granitic rocks that intruded the metavolcanic rocks. Pegmatites from the area gave an age of 1,799 million years.

The recent conclusions by Mukherjee et al. (1971) that "all the Precambrian rocks in the Flin Flon-Amisk Lake region are Aphebian in age" (whole rock Rb-Sr methods yield isochrons of 1775 $\pm$ 80 million years on Amisk Group volcanic rocks and 1805 $\pm$ 14 million years on Annabel Lake pluton) contradict an Archean age for the oldest rocks, at least at Flin Flon. It is apparent that further studies on the structural and metamorphic geology and additional Rb-Sr whole rock analyses and dates are needed to determine the time, extent, and intensity of orogenic events that affected the rocks of the Snow Lake-Flin Flon-Sherridon region.

Copper-Zinc Sulphide Deposits

Since 1930, the start of Hudson Bay Mining and Smelting Company's operation in the Flin Flon area, a total of 61 million tons of ore have been mined from nine separate base metal deposits in the Flin Flon-Snow Lake greenstone belt (Howkins and Martin, 1970). These deposits, together with developing mines and other mineral deposits are shown on Map 1.

Ore deposits in the Flin Flon area are considered by Howkins and Martin (1970) to have a definite stratigraphic control because they occur in the Amisk Group acid members between basic lava flows and/or pyroclastics. Shearing and folding segment the ore zones into many lenses and produce a patchy or "lace curtain" effect. Lineations are prominent and the ore lenses parallel the plunge of the lineations. The solid sulphide ores are fine-grained pyrite, or pyrrhotite, with varying amounts of chalcopyrite, sphalerite, and minor galena. Minor gold and silver are present. Sphalerite banding is common near the stratigraphic hangingwall, while chalcopyrite is generally more abundant on the footwall. Disseminated pyrite and chalcopyrite, with little or no sphalerite, occur either as separate zones or along the footwall and lower edges of the solid sulphide lenses. Metamorphic grade is low, ranging up to the greenschist facies.

Metavolcanics and metasediments of the Amisk Group and Kisseynew-type gneisses form the host rocks for the copper-zinc deposits of the Snow Lake area. Coarse-grained massive sulphides are common as a result of recrystallization of sulphides during a metamorphism that reached the almandine-amphibolite grade. Sphalerite does not exhibit banding and is disseminated throughout the sulphides. Sulphide textures, illustrative of recrystallization during metamorphism, have been found in the ore of Stall Lake Mines Ltd., No. 2 ore zone near Snow Lake (Coats, et al., 1970).

In the mines near Snow Lake, either pyrrhotite or granular pyrite can be the dominant sulphide. They are combined with chalcopyrite, sphalerite and scattered, euhedral, metacrysts of arsenopyrite. Pyrite metacrysts, eight to ten inches (20 to 25 cm) across, may also occur. The Snow Lake area deposits have a marked elongation along plunge, resulting in pencil-like orebodies with plunge-strike length ratios as much as 10:1 (Howkins & Martin, 1970).

Lithology

The geology of the Flin Flon area has been the subject of numerous publications since 1913, when the economic potential of the area began to be appreciated. The most detailed map of the immediate Flin Flon area is published at a scale of one inch to one thousand feet (Stockwell, 1960). Figure 4 is adapted from this map. A good general account of the geology and mineral deposits in the area appears in Byers, et al. (1965).

Amisk Group

The oldest, most widespread, and the economically most important rocks are those of the *Amisk Group*. Near Flin Flon, they are composed entirely of volcanic flow and fragmental units, and associated minor intrusions. The most abundant rocks of the group are pale to dark green weathering, fine-grained basalts and andesites. Dacite, rhyolite and quartz porphyry are less common, but the latter is of particular interest because it is closely associated with the ore zones at both Flin Flon and Schist Lake Mines. The flow rocks are often pillowed and amygdaloidal, and some units are characterized by the presence of epidotized feldspar phenocrysts. The coarser fragmental units can be massive and structureless, some are evidently autobreccias, but others are crudely bedded. The finer fragmental rocks may be well-bedded and are sometimes very finely laminated. They may show graded textures and local convolute bedding. Small sills and dykes are often recognized as the intrusive equivalents of the flow rocks. Larger, less regular bodies, mapped by Stockwell (1960) as meta-diorite and meta-gabbro, are probably also part of the Amisk Group.

Froese (1969) studied the chemistry of Amisk rocks from the area of the now abandoned Coronation Mine situated 15 miles (24 km) southwest of Flin Flon. He concluded that the rocks belonged to the basalt-rhyolite-dacite association of Turner and Verhoogen, although he pointed out that they are definitely not spilitic.

The base of the Amisk Group has not been identified. Estimates of its exposed thickness recognize the limitations imposed by the structural complexity of the area and range from 14,000 - 21,000 feet (4200 - 6300 m).

Cliff Lake Granodiorite

Controversy exists about the age of the Cliff Lake granodiorite. This rock is in faulted contact with units of the Missi Group (see below) about a mile (1.6 km) east of Flin Flon. Bruce (1918), Ambrose (1936) and Stockwell (1960) believed that the granodiorite was emplaced prior to deposition of the Missi, and they used the existence in the Missi of what they considered Cliff Lake granodiorite pebbles as evidence. This interpretation has since been dismissed and Byers, et al (1965) have pointed out the Cliff Lake rock closely resembles the definitely post-Missi 'quartz-eye' diorite of the Amisk Lake area.

Missi Group

The Amisk rocks are overlain, unconformably, by the cross-bedded sandstones and conglomerates of the *Missi Group*. Only locally is there any marked discordance between the Missi and the Amisk, and it seems likely that the latter were only slightly deformed before the Missi sedimentation. The Amisk units lying immediately below the unconformity sometimes show signs of intense, presumably subaerial, weathering. What are normally green rocks become dark, or black, to depths of up to 10 feet (3 m). They often show a patchy, cellular, structure that is suggestive of spheroidal weathering. This cellular structure has been found in pebbles within the Missi conglomerates. Other pebbles in the conglomerate are mainly Amisk Group volcanic rocks, and lesser amounts of granite, granodiorite, quartzite, chert, and jasper. The Missi sandstones have generally been referred to in the literature as arkose and greywacke, but Stauffer and Mukherjee (1971) state that the names sub-arkose and feldspathic greywacke of Pettijohn's classification are more appropriate. The Missi Group is thought to have accumulated in a fluvial environment (Byers and Dahlstrom, 1954, and Stauffer and Kukherjee, 1971).

The top of the Missi Group has not been recognized, but its exposed thickness has been estimated as being between 2,000 - 7,500 feet (600 - 2250 m) (Ambrose, 1936).

Post-Missi Intrusions

Excluding the Cliff Lake granodiorite, whose affinities remain in doubt, there are three main groups of post-Missi intrusions.

The *Creighton Lake granodiorite* pluton extends 12 miles (19 km) along the regional strike and is about 2.5 miles (4

km) wide. It is generally concordant with the Amisk host rocks. The southeast end of the body is exposed about 2 miles (3.2 km) west of Flin Flon. Its contacts with the Amisk rocks are sharp. Byers and Dahlstrom (1954) and Mukherjee, et al. (1971) have noted the presence within the pluton of rotated, foliated Amisk xenoliths. The rotation of these xenoliths in the boundary area and dilation associated with satellitic dykes, indicates that the granodiorite was emplaced as a magma (Byers, et al., 1965). Foliation and lineations are particularly well developed towards the margins of this pluton. These structures parallel those in the Amisk, and suggest that pluton emplacement was broadly syntectonic in relation to the main fold episode. However, certain features suggest that intrusion could have taken place during the later stages of this episode. Froese (1969) has described a second foliation that parallels the southeast margins of the pluton. This foliation occurs in both the granodiorite and in the surrounding Amisk rocks, and as it is oblique to Amisk structures that are thought to be associated with the main fold episode, it is believed to be younger.

The *Boundary intrusions* occur in a zone which crosses the Flin Flon area in a north-northwesterly direction. They are elongate to irregular shaped bodies that are up to a mile (1.6 km) long. These rocks are much coarser grained than the Amisk intrusions. They range in composition from peridotite to syenite and have a mean composition near gabbro. Individual bodies are characteristically heterogeneous with compositional extremes commonly occurring side by side. These intrusions are often crowded with xenoliths that are, in part, exotic. The Boundary intrusions cut the Creighton Lake granodiorites and are therefore younger (Byers, et al., 1965). The local development of foliation in the Boundary intrusions indicates that they must have been emplaced before the stresses associated with the main fold episode had finally subsided.

The *Phantom Lake granite* outcrops 4 miles (6.4 km) south of Flin Flon and has a maximum diameter of 2 miles (3.2 km). It is a massive, pink rock with large feldspar phenocrysts. Although younger than the Creighton Lake granodiorite, the contact relations between the Phantom Lake granite, and its related minor intrusions, and the Boundary intrusions suggest that the periods of emplacement of the latter two groups overlapped.

Although the chronological details of the post-Missi tectonic, metamorphic, and igneous events have yet to be solved, the broad outlines may be given.

The largest folds in the area are tight to isoclinal, and have axial plane traces trending N20°W. Axial planes are inclined at moderate to steep angles to the east. The folds are associated with a strong axial-plane foliation, and a lineation that plunges about 45° toward the southeast. The lineation is defined by elongated clasts and amygdules etc., in the Amisk, and by the elongation of pebbles etc., in the Missi. The pronounced orientation of amphibole needles in some Amisk rocks and of fine micaceous minerals elsewhere, indicates that in this area, regional metamorphism reached the lower greenschist facies during this fold episode. The major fold axes generally plunge to the southeast and are roughly parallel to the smaller linear structures. Exceptions occur in the Missi rocks where conglomerate bands define local basin structures that plunge to the north. In addition, in the area between Ross and Schist Lakes, the unconformity between the Missi and the Amisk dips north. This variation in plunge and dip, is independent of the major folding, and is due to an earlier fold episode about easterly-trending axes. The geometry of the early folds is discussed in Stauffer and Mukherjee (1971).

In the area north of Flin Flon, there are a number of curved faults. The most northerly, marks the contact between Amisk and Missi rocks. It is being referred to in the recent literature as the Club Lake fault but was earlier named the Creighton Creek thrust by Ambrose (1936). These faults were regarded as relatively late structures by Byers, et al. (1965) and by Stauffer and Mukherjee (1971). However, the authors believe that they are early, and perhaps due to thrusting from the south in association with the east-west folding. The fault curvature is assumed to have originated during the main fold episode and it can be geometrically related to the Hidden Lake syncline in the Amisk (Stockwell 1960). The Club Lake fault is cut by Boundary intrusions, and by dykes that may be related to the Phantom Lake granite.

In addition to the foliation associated with the main folding episode, there is a second, frequently strong, regional foliation, that strikes N20-30°E and dips at low to moderate angles to the southeast. There is no obvious folding asso-

ciated with this foliation and since it cuts the minor structures that are associated with the main folding episode it is evidently younger. The significance of this foliation is not clear, although it may have developed in response to the emplacement of the Creighton Lake granodiorite pluton as has been suggested by Byers, et al. (1965).

The latest structural events to affect the area include faulting, and the development of a major swing in the regional strike, from nearly north-south near Flin Flon, through northwest to approximately east-west some miles to the north (Map 1). The most important faults in the area strike a little to the west of north, and dip at moderate to steep angles to the east. Movement appears to have been in an oblique sense, with reverse, and left lateral components. Displacements on some of the faults are of the order of several thousand feet. Because of the off-setting relationships along the faults, and because of their varying degree of curvature in the area north of Flin Flon, Stauffer and Mukherjee (1971) have concluded that the periods of faulting and regional bending overlapped. The Cliff Lake fault shows the maximum curvature and is therefore early, the straight Ross Lake fault is late.

Flin Flon Mine

The Flin Flon copper-zinc deposit was discovered in 1914 but it was not until 1927 that the Hudson Bay Mining and Smelting Company was formed and production started in 1930. The original ore reserves were estimated at 18 million tons of 1.71% Cu and 3.5% Zn. By the end of 1970, a total of 59 million tons of 2.2% Cu and 4.4% Zn had been mined. Production is from two main shafts and the mine workings extend to the 3,700-foot (1125 m) level. The upper part of the orebody was mined by open pit but since 1942 production has been entirely from underground. Present operations are mainly confined to recovery of pillars and remnants. In addition to copper and zinc, other metals produced include gold, silver, cadmium, selenium and tellurium.

Geology

The deposit consists of six lenticular orebodies (Figure 5) within a shear zone that is 500 feet (150 m) wide and 2,000 feet (600 m) long and extends from surface to the 3,750-ft. (1125-m) level. The ore lenses average 900 feet (270 m) long, 70 feet (21 m) wide, 1,500 feet (450 m) in vertical depth, and 2,800 feet (840 m) along plunge. They occur in

Amisk volcanics near the hinge of a southerly plunging anticline on the west limb of the Burley Lake syncline. The ore zone strikes west of north, dips 70 degrees east and plunges 35 degrees southeast. It has a total length, along plunge, of 5,500 feet (1650 m).

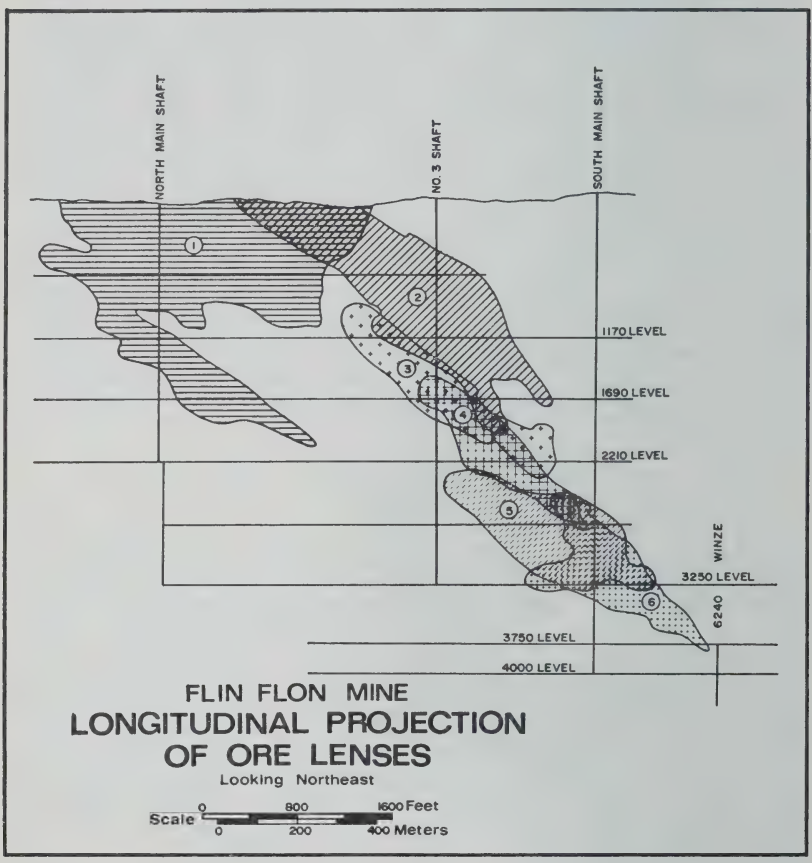

Fig. 5: Longitudinal projection of ore bodies, Flin Flon Mine, Manitoba-Saskatchewan.

The host rock for the ore is a quartz porphyry layer (Figures 6-8) that is bounded by andesite flows on the hanging wall and by sheared pyroclastic rocks on the footwall side. This assemblage of Amisk volcanics has been folded into a major anticlinal structure that has minor parasitic folds deve-

loped within the quartz porphyry. The ore lenses occur along the eastern limbs and in the crests of these minor folds. The major fold is believed to be related to the basic Boundary intrusive which invades the rocks in the mine area. This fold dies out below the 3,750-ft. (1125-m) level. A penetrative mineral lineation has developed in the enclosing schists. It plunges 35 degrees southeast, parallel to the fold axes and ore zones.

Shearing is prominent in the quartz porphyry and pyroclastic footwall rock but it terminates at the contact between the quartz porphyry and the hanging wall andesite. Footwall pyroclastics and portions of the quartz porphyry have been altered, across widths of as much as 1,000 feet (300 m), to chlorite schists containing lesser amounts of talc and sericite. Diorite dykes and sills occur as waste blocks within the ore zones and are relatively unaltered. Metamorphism is low-grade and ranges up to the greenschist facies. The deposits exhibit a definite stratigraphic control as they occur in the acid volcanics beneath basic flows.

Mineralization

The two distinct types of ore are *solid sulphide* and *disseminated sulphide.*

The *solid sulphide* ore constitutes 70 per cent of the total and consists mainly of fine-grained pyrite with varying amounts of chalcopyrite and sphalerite. Vertical and horizontal zoning of sulphides is evident. Chalcopyrite occurs irregularly throughout the sulphide however is more abundant towards the footwall. On the hanging wall, sphalerite occurs interlayered with the pyrite and forms a banded sulphide ore. Copper and zinc grades increase with depth. Gold and silver, largely as tellurides and selenides, occur in the solid sulphide ore.

The *disseminated sulphide* ores consist of chalcopyrite and pyrite scattered through chlorite and/or talc schists. These ores occur on the footwall side and along the lower edges of the plunging solid sulphide bodies. Although smaller and more irregular than the solid sulphide bodies, disseminated ore zones often contain hundreds of thousands of tons of ore. Chalcopyrite is found as irregular sulphide veinlets throughout the schist however pyrite tends to parallel the foliation of the rock. These ores contain no gold or silver and only minor amounts of sphalerite. The talc schists decrease in abundance with depth.

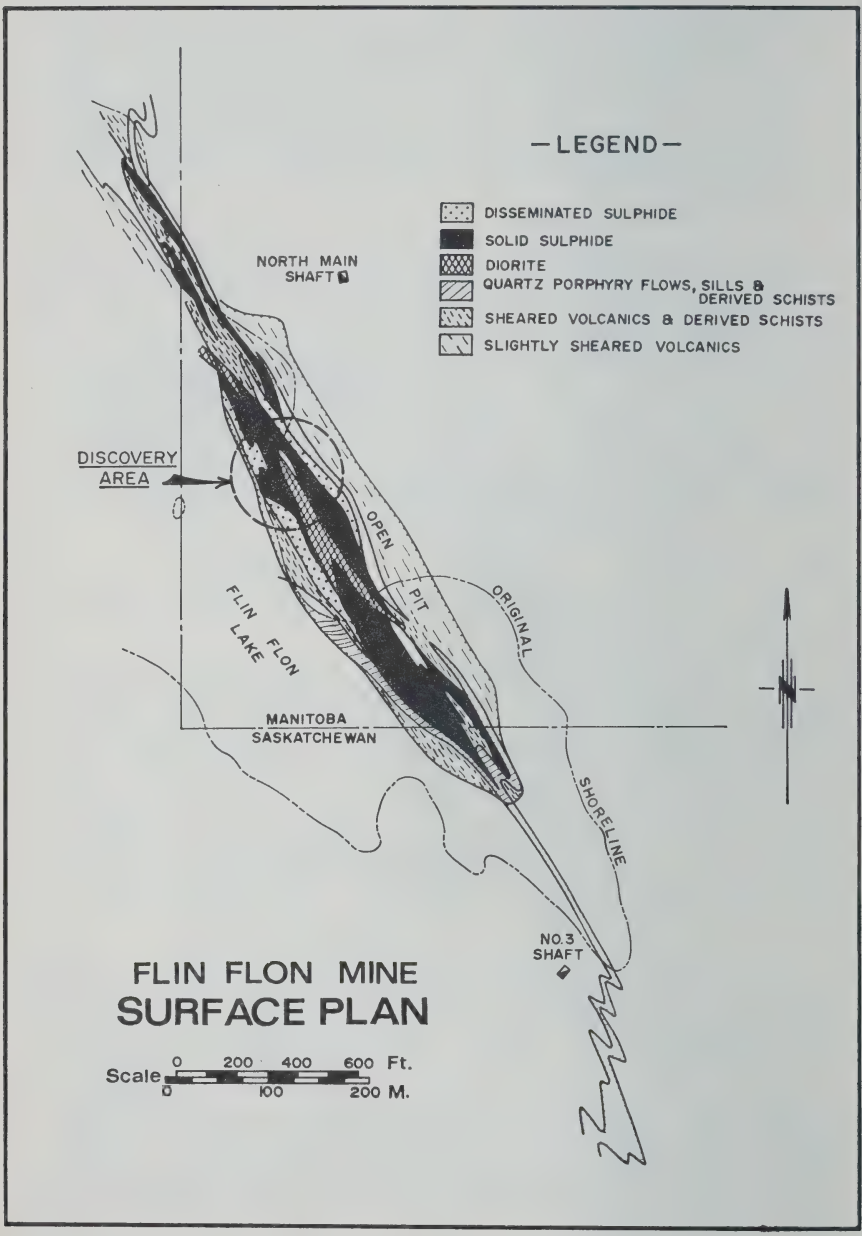

Fig. 6: Surface geological plan, Flin Flon Mine.

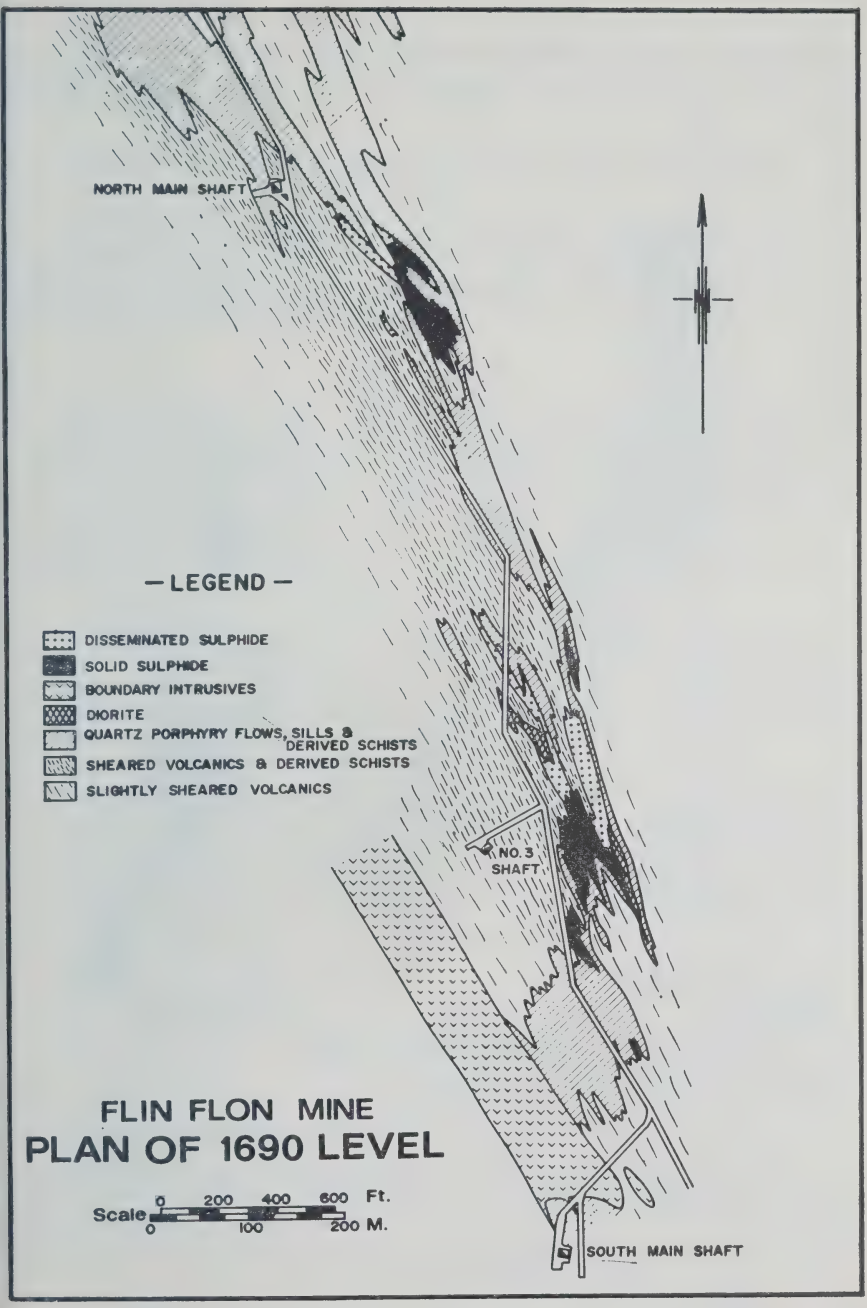

Fig. 7: Geological plan of the 1690 level, Flin Flon Mine.

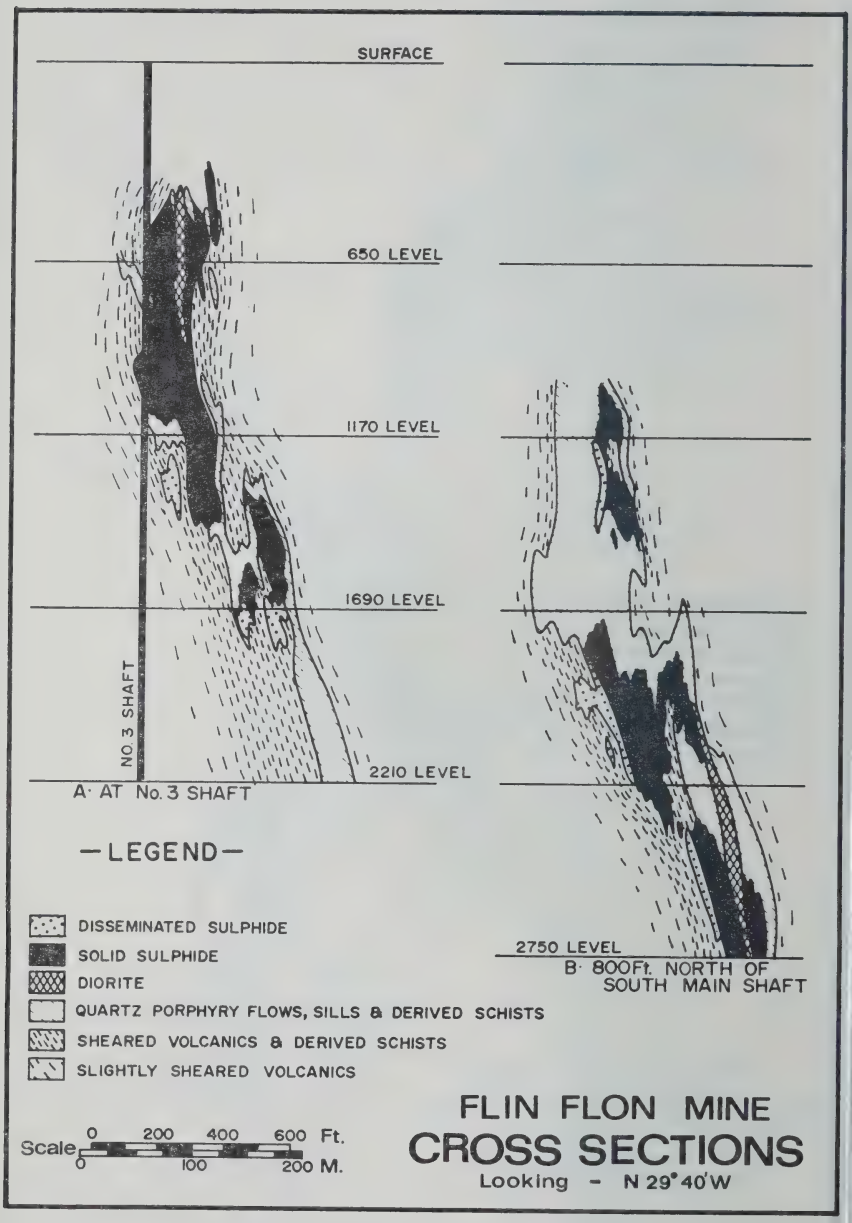

Fig. 8: Cross sections, Flin Flon Mine.

Exploration work carried out to the 5,000-ft. (1500 m) horizon has failed to extend the ore-zone below the 3,750-ft. (1125-m) level.

Regional Geology of the Lynn Lake-Southern Indian Lake Area

The Lynn Lake-Fox Lake area covers a small portion of an extensive sequence of volcanic and sedimentary rocks. These rocks outcrop over an area 200 miles (320 km) long by 40 miles (64 km) wide (Map 2).

Geology

The rocks have been subdivided into two groups: the older Wasekwan Group, and the younger Sickle Group. The Sickle rests disconformably on the Wasekwan at most localities, but locally, the two are separated by a pronounced angular unconformity or nonconformity. Table 2 shows the regional stratigraphic column. Within the Wasekwan and Sickle Groups, the units are listed lithologically and are not necessarily in chronological order.

Pre-Wasekwan rocks have not been recognized in the complex. The lowermost unit in the *Wasekwan Group* is a conglomerate with greywacke interbeds. It only occurs in the Cockeram Lake area, east of Lynn Lake. The conglomerate contains rare fragments of granite which are considered evidence for a pre-Wasekwan orogenic cycle.

The early, fine-grained sediments of the Wasekwan Group were probably derived from volcanic rocks. This volcanic activity gradually increased and reached a maximum when thick, widespread, Wasekwan lavas and pyroclastics were extruded. Sedimentation during the same period appears to have been restricted to small basins, rather than thick, widespread accumulations.

Post - Wasekwan intrusions include: gabbro, diorite, quartz diorite, granite, and minor pegmatite. Milligan, (1960) noted some 40 varieties of intrusive rocks and grouped them into four major rock units. During, and following the emplacement of the intrusions, the Wasekwan Group was uplifted, folded, and locally granitized.

Rocks of the *Sickle Group* are the only post-Wasekwan sedimentary rocks recognized in the area. The base of the unit is marked by a thick basal conglomerate that can be traced laterally for some 120 miles (192 km). The unit maintains a relatively uniform thickness throughout its en-

tire length, but because it is often in sheared contact with older rocks, and may have been isoclinally folded, its maximum thickness is not known. This conglomerate may have also filled local, small basinal depressions in older rocks (Campbell, 1970, in preparation). The conglomerate contains clasts that range from Wasekwan sedimentary and volcanic rocks, to pre-Sickle intrusive rocks, and pinkish quartzites.

TABLE 2

TABLE OF FORMATIONS
(After Milligan, 1960)

POST-SICKLE INTRUSIVES

22—Quartz porphyry; quartz-feldspar porphyry.
19—Pegmatite, aplite.
18—Pink and grey biotite and hornblende granite and granodiorite.
17—Siliceous hornblende-biotite tonalite, (age doubtful).
16—Black Trout diorite.

SICKLE GROUP

14—Arkose, quartzite, greywacke, minor pebble beds. Local amphibolite derived from pillow basalt. Minor pyroclastics.

13—Conglomerate, derived schists.

Kisseynew-type gneisses (some probably derived from Wasekwan sediments).

24—Quartz - biotite - hornblende - plagioclase gneiss, locally garnetiferous.
23—Stratiform granitoid paragneiss, undifferentiated granite gneiss.
21—Plagioclase-amphibole bands, probably derived from lime-rich sedimentary layers.
20—Feldspathic muscovite-biotite schist derived from arkose. Local pebble beds.

UNCONFORMITY

POST-WASEKWAN INTRUSIVES

12—Pink to buff biotite and hornblende granite, massive to gneissic.
11—Grey, massive to gneissic, hornblende-biotite granodiorite. Minor diorite and leucotonalite.
10—Grey hornblende-biotite diorite, quartz diorite; minor included volcanic rocks.
9—Gabbro, norite, hornblendite, minor diorite. Possibly some massive flows.

WASEKWAN GROUP

8—Banded iron formation and slates.
7—Tuff, agglomerate, volcanic breccia; some interbedded sedimentary rocks.
6—Rhyolite and trachyte.
5—Amphibolites derived from andesite and basalt; minor interbedded pyroclastics, some trachyte.
4—Predominantly impure quartzite, minor conglomerate and interbedded lavas, pyroclastics and greywacke.
3—Interbedded sedimentary and/or tuffaceous rocks.
2—Greywacke, quartzite, undifferentiated pyroclastics, minor iron formation.
1—Conglomerate and zones with conglomerate lenses.

The members of the Sickle Group grade rapidly upward into finer-grained rocks. The group is characterized by a marked uniformity throughout the entire area. A thin horizon of metamorphosed pillow basalt and minor volcanic breccia occurs in the Sickle Group, near the base of the sequence, at Granville and Suwannee Lakes. This remarkably continuous unit represents the only known volcanic rocks within the Sickle Group. Amphibolites derived from these volcanic rocks have been mapped from Granville Lake in the north to Notigi Lake in the south. The amphibolite layer is the sole marker horizon within the Suwannee-Rat-Notigi area, (Elphick, 1969; Campbell, 1969), and it forms the contact between magnetiferous arkosic sediments and fine-grained pelitic rocks.

Post-Sickle intrusions range in composition from granite to gabbro. The Black Trout diorite, the oldest intrusive in this group, has a very limited distribution. Much larger areas are underlain by post-Sickle-tonalite and granite.

Southwest of Lynn Lake, Wasekwan and Sickle rocks have been mapped as gradational into *Kisseynew-type gneisses.*

Milligan (1960, pp. 117-156) gives an excellent outline of the post-Sickle deformation.

Geology of the Lynn Lake-Fox Lake Region

The road between Lynn Lake and the Fox Lake Mine traverses an area underlain by Wasekwan Group rocks and Pre-Sickle intrusives. Access to rocks of the Sickle Group is obtained by the side road to McVeigh, approximately midway between Lynn Lake and Fox Lake (Figure 9).

Lithology

Wasekwan Group

The Wasekwan Group contains varied lithologies, especially in the vicinity of Lynn Lake, and to the south, where pyroclastics, sediments, agglomerates, flow breccias and flows of varying composition are intermixed. The following descriptions of the various types and varieties are adapted from Milligan (1960). No attempt is made to describe the intermingled rocks of separate map areas.

The most abundant and widespread sedimentary unit in the Wasekwan is a *quartz-mica gneiss* or *schist,* usually referred to as *greywacke.* This is a medium to dark grey rock with a decided brownish shade and sandy appearance. It is

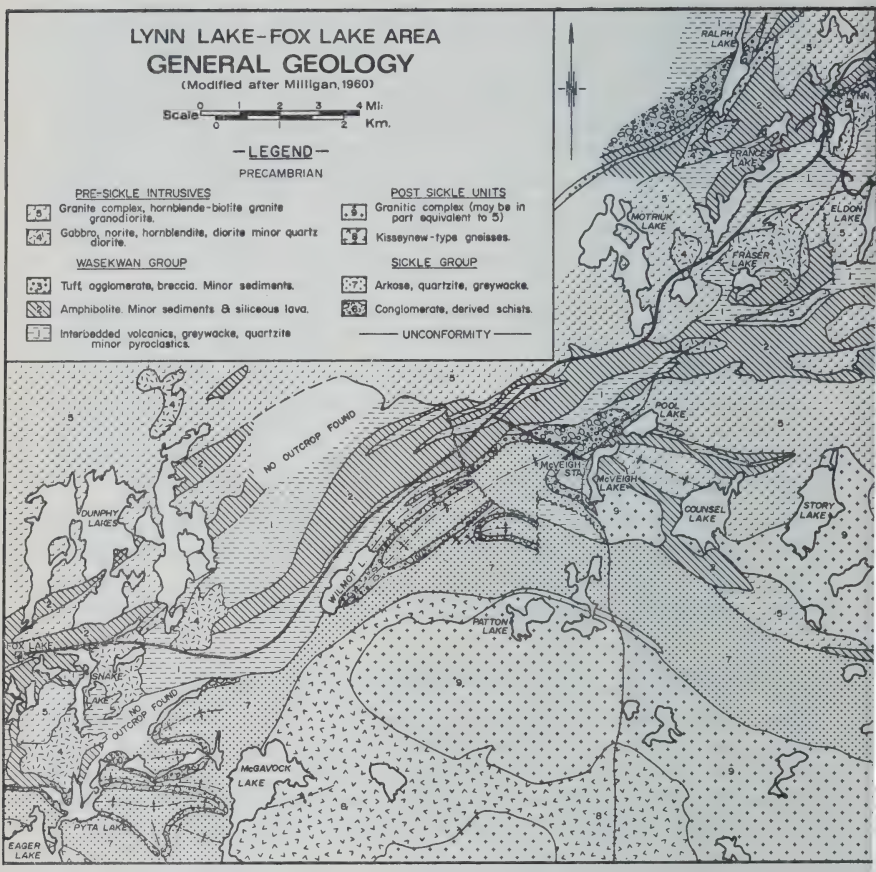

Fig. 9: General geology of the Lynn Lake-Fox Lake area, Manitoba.

composed of quartz and dark brown, or black, biotite in a matrix of grey feldspar. Though quartz may not be readily apparent megascopically, it is usually present in amounts from twenty to sixty per cent. The feldspar is dominantly plagioclase, but a few grains of orthoclase or microcline have been reported in some sections. The amount of feldspar seldom exceeds that of quartz, but biotite may be as high as fifty-five per cent. Hornblende is a minor constituent at some localities. Variations in mineral assemblage, and in the grain size, reflect the metamorphic grade. Higher grade metamorphism at some localities is indicated by the

presence of garnet, staurolite, and sillimanite. Of these, garnet is the most common. Distinct bedding planes are evident in many outcrops, however in some cases recrystallization has destroyed the thinner laminae, and left only broader, compositional banding. Consequently, bedding may range from minute layering to essentially uniform bands several feet, or tens of feet, in thickness.

Impure quartzite is also a common Wasekwan sediment. It is the dominant rock in the type area at McVeigh Lake, southwest of Lynn Lake, and in the vicinity of Frances and Lynn Lakes. It appears to be less abundant elsewhere, and constitutes only a minor part of the Wasekwan Group in the western part of the area. The extensive quartzites between Lynn Lake and Frances Lake contain less interbedded volcanic flow and tuffaceous material than is usual elsewhere. The quartzites are well-bedded, fine-grained rocks, that weather light grey, buff, or almost white. Fresh surfaces are grey in colour and exhibit abundant tiny micaceous flakes. The impure quartzites consist, in order of abundance, of quartz, biotite, muscovite, and feldspar. Hornblende is a minor constituent at some localities. Between Frances Lake and the Fraser Lake gabbro, the quartzite contains small lenticles of biotite. Mafic volcanic rocks form the major portion of the Wasekwan Group. They are amphibolite (andesite and basalt) and are commonly refered to as greenstones, though in most cases, they are not green chloritic schists but black amphibolites. The typical greenstone of the district is dark grey to greenish black on the weathered or glacially polished surface. The more feldspathic varieties show small white specks of feldspar on the weathered surface. The fresh rock is shiny black, greenish black, grey, or black and white, depending upon composition and grain size. Basaltic varieties are composed of 70 per cent, or more, black hornblende crystals that range from very small to about one-quarter inch (0.6 cm) in length. In the coarser, more mafic varieties, the basalts are indistinguishable, in hand specimen, from the gabbro or diorite of the district. Feldspar composition reflects the metamorphic grade and is oligoclase or andesine in most places. The basic lavas of the Counsell Lake and Wilmot Lake areas are composed of 50 to 60 per cent hornblende in a matrix of fine-grained plagioclase and quartz. The hornblende is commonly oriented in the plane of foliation and is poikiloblastic.

Flow breccia outcrops towards the southern end of the east side of Ralph Lake. The matrix of the breccia approximates

that of some adjacent fine-grained flows and is dark greenish-black, slightly schistose, with minute hornblende needles. The matrix foliation flows around the fragments to some extent. Fragments are generally lighter coloured than the matrix. Rounded feldspar grains make up 50 to 60 per cent of the matrix and give the rock a speckled appearance. Some fragments weather green and contrast with the predominant buff to brownish grey of those with a high feldspar content. Fragments range in size from 2 inches (5 cm) to as much as 24 inches (60 cm) across.

Agglomerate, although not abundant, does occur at several widely separated places. It is found to the north and west of Lynn Lake and at Dunphy Lakes. At Dunphy Lakes the agglomerate contains bombs of amygdaloidal basalt, rhyolite, with contrasting zones of smaller bombs and lapilli. On the east side of Ralph Lake the groundmass of the agglomerate is a dark green aggregate of small hornbende needles. Fragments are light grey, or greenish, on the weathered surface; most of them are elliptical and of varying sizes. Metamorphism causes the increased development of hornblende and feldspar in the agglomerate and as a result, fragment outlines become increasingly less distinct.

Pre-Sickle Intrusives

A wide range of rock types are included within the Pre-Sickle Intrusives (Units 4 and 5, Figure 9). The most extensively distributed mafic types are gabbro and norite, followed by diorite, quartz diorite, oligoclase granite and granodiorite. At Lynn Lake, the gabbro includes zones of peridotite and quartz-hornblende diorite. Copper-nickel orebodies are presently being mined from this rock and it is generally referred to as the Lynn Lake gabbro. It will be described more fully in the section on the Lynn Lake Mine.

Sickle Group

The Sickle Group type locality is at Sickle Lake, 20 miles (32 km) southeast of Lynn Lake (Figure 3). Sickle rocks outcrop in an arcuate band between Eager Lake and a point south of Story Lake (Figure 9). A smaller unit underlies an area at Ralph Lake. Although, in the past, there has been considerable doubt about the age relationships between the Sickle and Wasekwan Groups, the general opinion of Manitoba Mines Branch geologists is that the Sickle sediments rest unconformably on the Wasekwan rocks. At Pool Lake, (Figure 9), pebbles in the conglomerate have been derived from the adjacent post-Wasekwan (?) quartz diorite.

The Sickle Group is composed of metamorphosed sedimentary rocks that show a wide range of metamorphic grade. The original minerals and small textural features have generally been obliterated. The series is composed of a conglomerate band at, or near, the base. This is overlain by rocks which are interpreted to have been arkoses, impure sandstones (subarkoses?), greywackes and shales. Lime carbonate rocks do not occur, but their former existence is inferred from the presence of amphibolite which is probably the metamorphic equivalent of calcareous shales and marls.

The unaltered *conglomerate* is composed of 10 to 65 per cent pebbles in a quartz-feldspar-mica matrix. The pebbles average about 1 to 3 inches (2.5 - 7.6 cm) in diameter, and range up to boulder size. They include quartzite, greywacke, arkose, chert, greenstone, feldspar, vein quartz, schist and granite. The conglomerate grades upward into about 1,000 feet (300 m) of arkose that contains numerous conglomerate lenses. These conglomerates may be schistose.

The larger part of the Sickle Group is a thick assemblage of metamorphosed sedimentary rocks that presumably were originally *arkose, sandstone, greywacke* and *shale.* The least altered rocks are in the biotite zone of metamorphism, and are composed of quartz, feldspar, and biotite. Maximum thickness of this sequence is about 9,000 feet (2700 m).

Kisseynew-type Gneises

The Kisseynew-type gneisses (Unit 8, Figure 9) are a group of medium- to high-grade metamorphic rocks of wide lithological variety. The larger part of this unit was derived by the metamorphism of rocks of the Sickle Group, but it is also possible that some of the gneisses were derived from Wasekwan rocks. The extensive muscovite-biotite schist at Eager and McGavock Lakes, is considered to be a product of the relatively low-grade metamorphism of Sickle sediments.

Stratiform granitoid paragneiss, the most extensive form of Kisseynew-type gneiss, is difficult to distinguish from granite. In many places it contains abundant stringers and dykes of aplite and pegmatite. In the coarser-grained parts, layers several hundred feet thick are recognizable as probable former sedimentary units. Northeast of McGavock Lake the gneiss is characterized by quartz-sillimanite knots and is considered to have been derived from arkose and greywacke by high-grade metamorphism.

Post-Sickle Intrusives

Intrusive rocks that range from gabbro and diorite, to granite, invade units of the Sickle Group. Granitic rocks form several large bodies, predominantly within the area of Kisseynew gneiss. A granite plug occupies about 20 square miles (51 sq. km) of the area, south of Patton Lake.

Lynn Lake Mine

The Lynn Lake Mine, owned and operated by Sherritt Gordon Mines Ltd., was discovered by prospecting in 1941. Sufficient ore had been outlined by 1950 to support the cost of plant and railway construction and production of the first copper-nickel concentrate began in 1953. Ore reserves, estimated at the end of 1970, totalled 12,600,000 tons averaging 0.77 per cent Ni, and 0.38 per cent Cu including 12½ per cent dilution. The ore from the "EL" orebody was of significantly higher grade than the other ores. When production began, the 2.4 million ton "EL" orebody averaged 2.5 per cent Ni and 0.93 per cent Cu. The "EL" orebody was mined out at the end of 1963.

Geology

Twelve copper-nickel orebodies occur entirely within the post-Wasekwan mafic intrusive complex referred to as the *Lynn Lake gabbro* and one occurs in the small "EL" gabbro plug that lies southeast of the main mass. The Lynn Lake gabbro is an elliptical, pipe-like body 12,000 feet (3600 m) long and 5,000 feet (1500 m) in greatest width. It intrudes, with discordance, a sequence of mafic, intermediate and acid volcanic flows, breccias, tuffs and sediments of the Wasekwan Group. The rocks of the intrusive mass, and its contacts with the enclosing wall-rocks, are poorly exposed. Most of the area underlain by the intrusion is low-lying and covered by muskeg and lake.

The "EL" gabbro, a small, pipe-like, mafic body, 1,200 feet (360 m) in diameter, lies approximately 3,000 feet (900 m) southeast of the south end of Lynn Lake. Its shape and extent have been determined by drilling. The appearance and mineralogy of this complex are similar to those found in the Lynn Lake gabbro.

The principal components of the intrusive rocks are diorite and gabbro that have a medium- to coarse-grained, granitoid texture. Either variety may grade abruptly to amphibolite but sharp contacts between any of these rocks are rare. Acti-

nolite is the chief ferromagnesian mineral and labradorite is the most abundant plagioclase.

Norite is a less common member of the basic complex. It occurs as small, poorly defined masses in, or near, the ore zone, and as small blocks or fragments (residuals) within the ore zone. The ferro-magnesian mineral is enstatite.

Peridotite occurs as individual lenses, or irregular masses, in the vicinity of the orebodies. It is a dark, medium-grained, mottled serpentinized or talcose rock, with a small amount of very finely divided magnetite. Olivine is present in the less altered phases. The peridotite appears to be younger than all of the other members of the group except quartz-hornblende-diorite. The peridotite has only been observed underground and in diamond drill holes. At surface it underlies low ground.

Quartz-hornblende-diorite, locally known as "Q.H.D.", is a hard, brittle rock of intermediate to basic composition. It is characterized by its fine-grained texture and somewhat variable appearance, and by the presence of quartz grains. It is later than all other members of the Lynn Lake gabbro, and occurs as large, irregular, masses and as long persistent dykes of variable width.

Ruttan (1955) considers that the Lynn Lake basic intrusive complex was formed by multiple intrusion into folded and deformed Wasekwan rocks and that it has remained *in situ,* in its near vertical position, since emplacement.

Studies by Emslie and Moore (1961) lead them to conclude that the Lynn Lake gabbro is a strongly differentiated layered intrusion that crystallized in a horizontal attitude and was subsequently tilted to vertical position. They visualized a sequence of almost completely uralitized rocks that ranged from ultramafic at the base, through pyroxenites and norites, to normal gabbro in the upper part of the intrusion.

Structural Geology

Major faults have been recognized in the area (Ruttan, 1955). The Laurie River fault passes through Ralph Lake and lies approximately 3 miles (4.8 km) west of the mine (Figure 9). Two related faults, the Lynn Lake and Eldon Lake faults strike in a slightly more easterly direction. They occur on each side of the Lynn Lake ore zone and are about 1.5 miles (2.4 km) apart. Their dip is steep and to the west. The Laurie River, Lynn Lake, and Eldon Lake faults are believed to be the result of a thrust from the west. The stress

was sufficient to create major and complementary breaks, and may have been responsible for local folding along a north-south-trending axes.

In the immediate vicinity of Lynn Lake, the movement on the faults lying within the basic plugs resulted in an intricate system of shears and breccia zones that are considered by Ruttan to have become areas suitable for ore deposition. In the stratified rocks, much of the adjustment took place along bedding planes.

Emslie (1961) has suggested that the "EL" gabbro is part of the main intrusion and that it was separated from it by an inferred fault that trended southeast from the south end of the Lynn gabbro and passed north of the "EL" gabbro. This view is not held by Ruttan.

Mineralization

All of the orebodies are vertical to steeply dipping pipe-like bodies that are irregular in both horizontal and vertical dimension. A projection of the plan view of the orebodies is shown in Figure 10 and a plan of the geology on the 2,000 level in Figure 11. The ore has been classified by Ruttan (1955) into three main physical groups:

(1) *Massive sulphide ore;* sulphide minerals either predominate over, or occur to the exclusion of, silicate minerals.

(2) *Disseminated sulphide ore;* irregular blebs and grains and grains of sulphide minerals are distributed through the rock.

(3) *Breccia ore;* rounded to angular fragments of a variety of rock types including norite, gabbro, amphibolite, vein quartz, felsite and granite, occur in a matrix of massive sulphide ore. The fragments are usually barren of sulphides.

The sulphide minerals, in order of decreasing abundance, are pyrrhotite, pentlandite, chalcopyrite and pyrite. Minor cobalt, zinc and gold occur. The pentlandite commonly forms well-defined veinlets in the pyrrhotite. Ore sulphides occur in amphibolite, diorite, norite, quartz-hornblende diorite, peridotite, and in the various dykes and veins that intrude the basic plugs. Orebodies have been found in amphibolite, gabbro, norite and "Q.H.D." and they extend from one rock type to another.

Several authors (Allan, 1948; Hunter, 1950; Ruttan, 1955; Milligan, 1960; Emslie and Moore, 1961) have proposed a number of conflicting opinions on the mode of origin of the

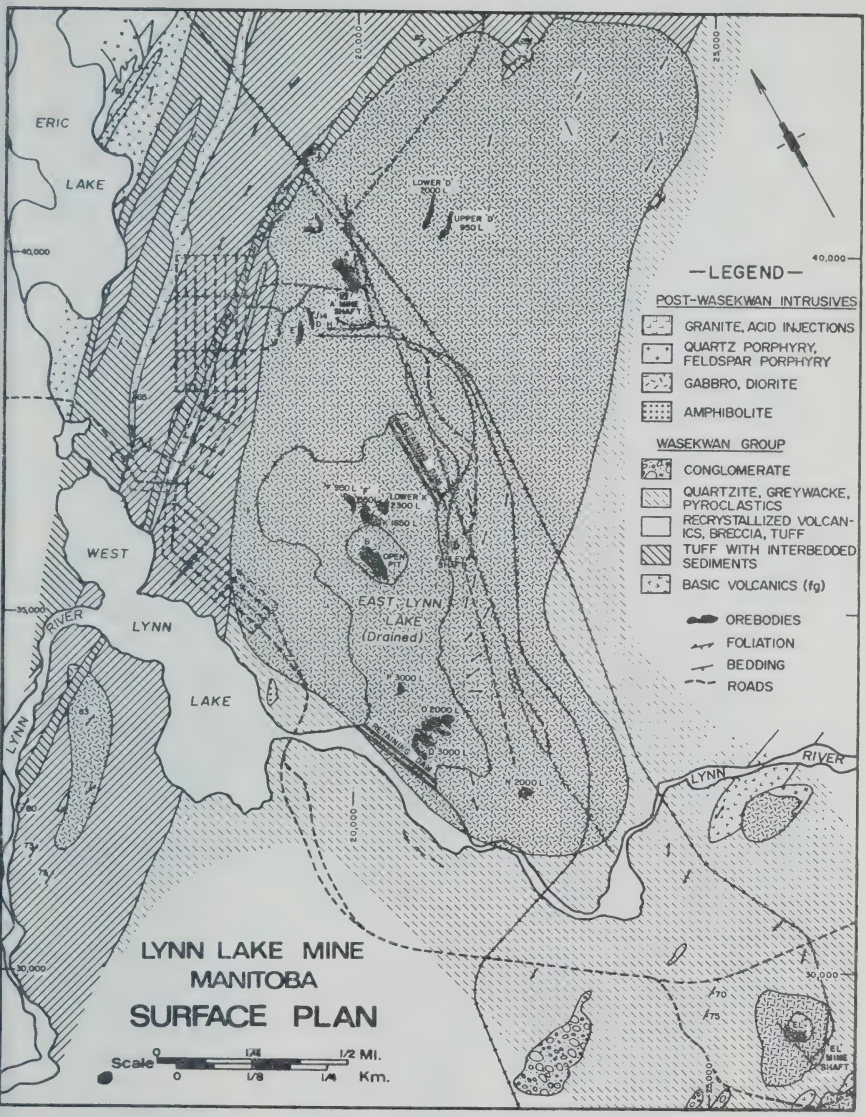

Fig. 10: Surface geological plan of the Lynn Lake Mine. Orebodies projected to surface.

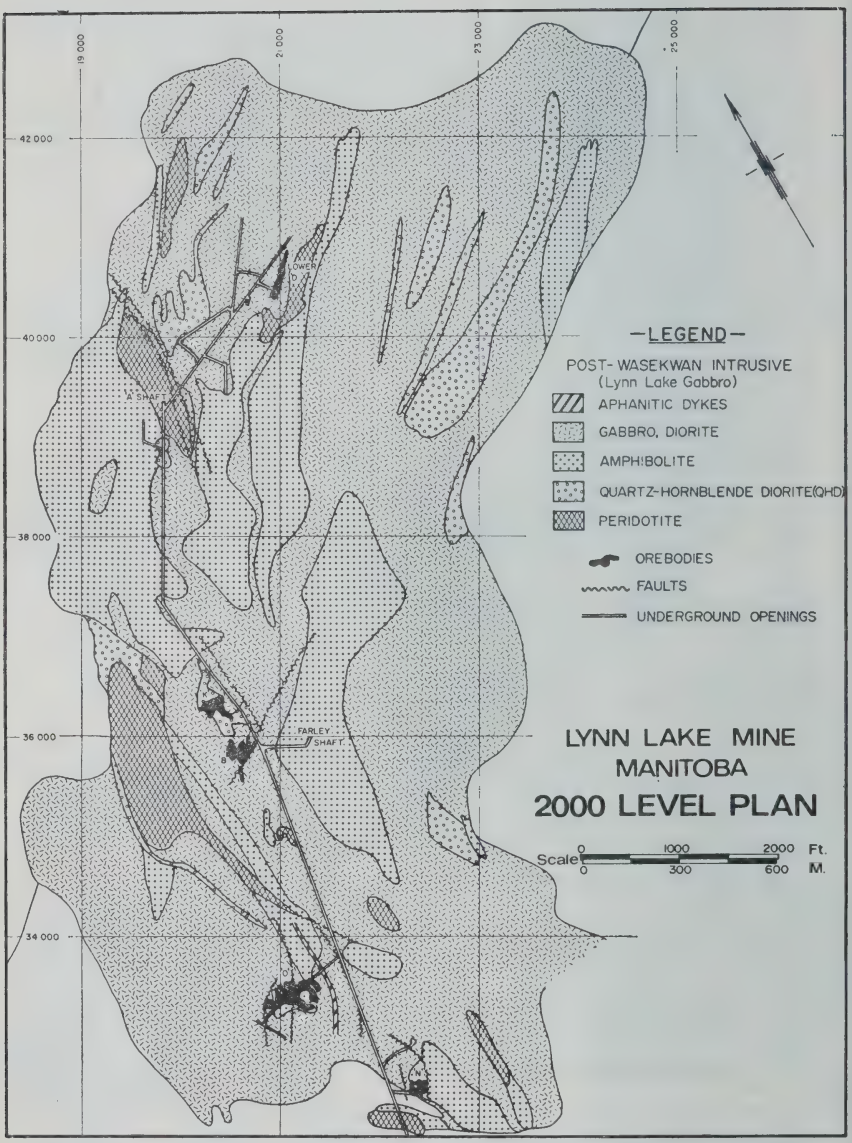

Fig. 11: Geological plan of the 2,000 level, Lynn Lake Mine, Manitoba.

Lynn Lake sulphide ore. Allen (1948) gave evidence to support a hydrothermal hypothesis of ore deposition from solutions that may or may not have been genetically related to the mafic intrusion. Hunter (1950), studied the petrography of the intrusion in greater detail and decided that magmatic segregation was the ore-forming process. Ruttan (1955) favoured a hydrothermal origin and suggested that the formation of orebodies might be related to a nearby granite. Milligan (1960) reviewed the previous work and favoured the hydrothermal hypothesis, finding the available information not reconcilable with a magmatic origin for the ore. Emslie and Moore (1961) gave evidence that points to the development of the nickel-copper deposits by crystallization from an immiscible sulphide liquid within the gabbro. They supported their arguments by a study of trace element trends in the gabbroic rocks and by comparing their results with the results of similar studies of other differentiated mafic intrusions.

Fox Mine

The Fox Mine copper-zic deposit of Sherritt Gordon Mines Ltd. is located 27 miles (43 km) west-southwest of Lynn Lake. It was discovered in 1961 when a strong horizontal loop electromagnetic anomaly, that had been indicated in airborne electromagnetic and magnetic survey results, was diamond drilled. Ore reserves indicated from surface diamond drilling, were calculated between surface and the 2000 level, at 12,269,000 tons containing 1.74% copper and 2.35% zinc. Ore reserves on December 31, 1970 were 13,100,000 tons grading 1.84% copper and 2.70% zinc.

Production commenced in 1970 at the rate of 1 million tons per year by sublevel open stoping. The mine is serviced by one shaft with main accesses and haulages established at 400 foot (120 m) vertical intervals to the 2000 level. The ore is processed at the mine site to produce copper and zinc concentrates. Copper concentrates are shipped to Mitsubishi Metal and Mitsubishi Shoji in Japan and zinc concentrates to Hudson Bay Mining and Smelting in Flin Flon. Minor amounts of gold and silver are recovered from the copper concentrate and cadmium from the zinc concentrate.

Geology

The deposit occurs in a belt of isoclinally folded metavolcanics and metasedimentary rocks that are primarily Wasekwan Group with subordinate amounts of Sickle Group ar-

koses (Stanton, 1949; Milligan, 1960). The strata dip steeply to the northwest and they are overturned to the south with the axial plane trending N75°E (Stanton 1949). These rocks are considered to be Archean and to have undergone regional Kenoran and Hudsonian deformation and metamorphism (Stockwell 1964). For the most part, the metavolcanic and metasedimentary rocks have been metamorphosed to the almandine-amphibolite facies. Locally, however, especially in the immediate vicinity of the ore zone, some retrograde greenschist facies rocks occur. The Wasekwan metasediments and metavolcanics have been invaded by stocks and dykes of granodiorite, granite, diorite-gabbro, amphibolite and felsite. Although the Sickle Group arkoses apparently are not intruded to the same extent, they appear to be as deformed and metamorphosed as the Wasekwan series and their associated intrusives. In the mine, the Sickle Group appears to be conformable with the Wasekwan and not in fault contact as described by Milligan (1960).

The stratigraphy in the immediate vicinity of the mine is illustrated in Figures 12, 13, 14 and 15. Although highly metamorphosed, the rock units are recognized as having been derived from a largely volcanic sequence of intercalated intermediate flows and pyroclastic material with some associated sedimentary beds. The principal rock units are identified as quartz-hornblende and quartz-hornblende-biotite gneisses, slatey sediments, arkose, quartzite and andesite. The gneisses are variable in composition and composed of quartz, feldspar, hornblende, biotite, garnet, muscovite and sericite. Stratigraphic tops have not been determined in the mine workings.

The metavolcanics and metasediments are intruded by extensive dykes of diorite-gabbro and lesser amounts of porphyritic gabbro, amphibolite, granite, and felsite. The granite and felsite predate the diorite-gabbro, porphyritic gabbro and amphibolite. These dykes are concordant and/or discordant and exhibit a gneissosity, similar to that of the country rock.

A distinct penetrative mineral and clast lineation, developed on the planes of the gneissosity, plunges N50°W at 75°, subparallel to the plunge of the orebody. Faults trending due north and dipping at 35° to the west, transect the ore zone and the country rocks, and appear to be late. The ore zone, however, has not been appreciably dislocated by faulting.

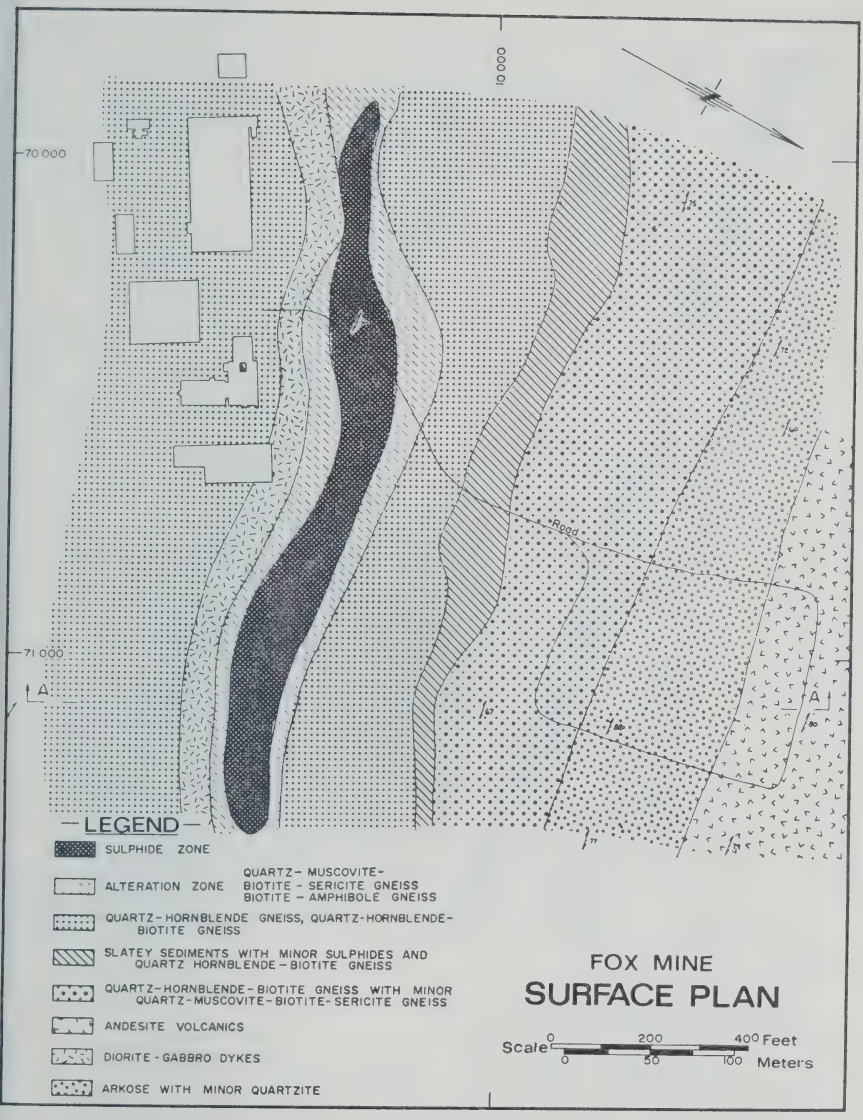
10 000
70 000
71 000
A
A
Road
— LEGEND —
SULPHIDE ZONE
ALTERATION ZONE
QUARTZ - MUSCOVITE - BIOTITE - SERICITE GNEISS
BIOTITE - AMPHIBOLE GNEISS
QUARTZ - HORNBLENDE GNEISS, QUARTZ - HORNBLENDE - BIOTITE GNEISS
SLATEY SEDIMENTS WITH MINOR SULPHIDES AND QUARTZ HORNBLENDE - BIOTITE GNEISS
QUARTZ - HORNBLENDE - BIOTITE GNEISS WITH MINOR QUARTZ - MUSCOVITE - BIOTITE - SERICITE GNEISS
ANDESITE VOLCANICS
DIORITE - GABBRO DYKES
ARKOSE WITH MINOR QUARTZITE
FOX MINE
SURFACE PLAN
Scale
0 200 400 Feet
0 50 100 Meters

Fig. 12: Surface geological plan of the Fox Mine.

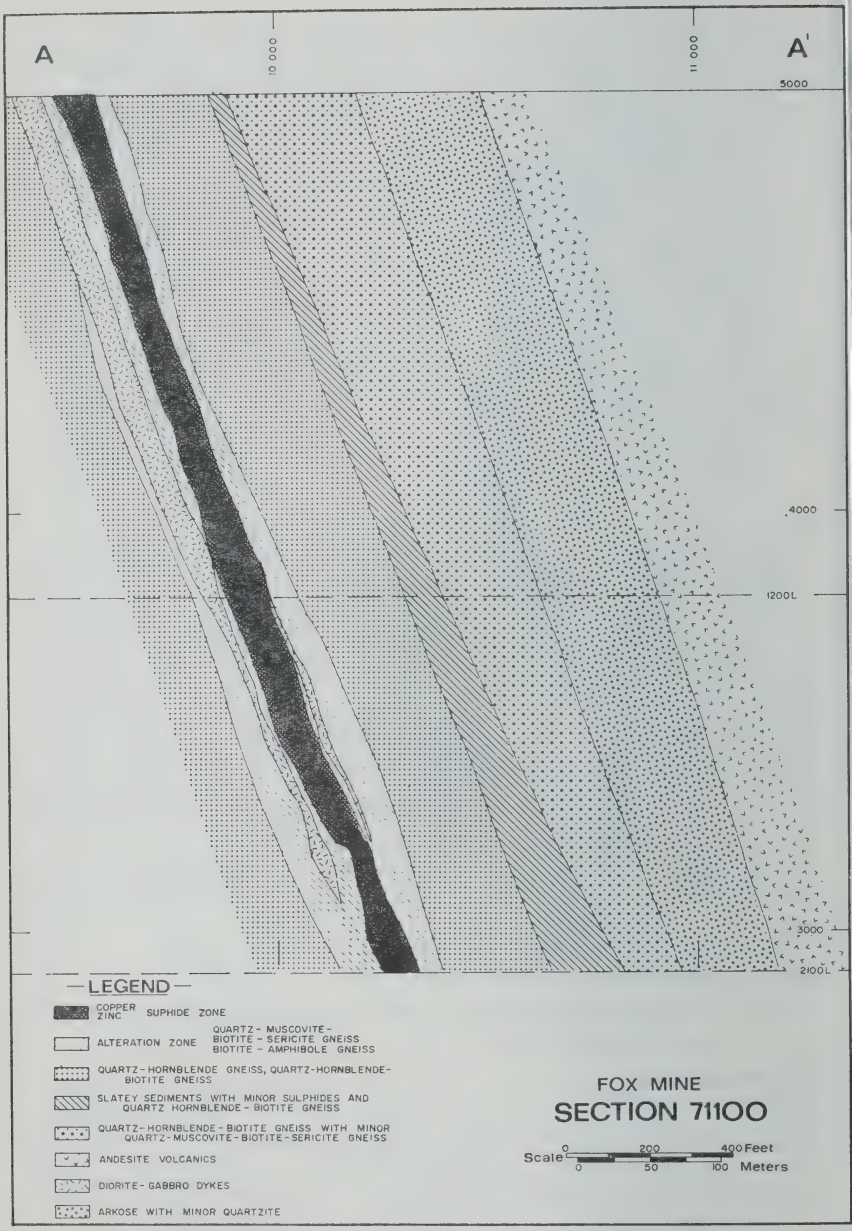

Fig. 13: Cross section 71100, Fox Mine, looking west.

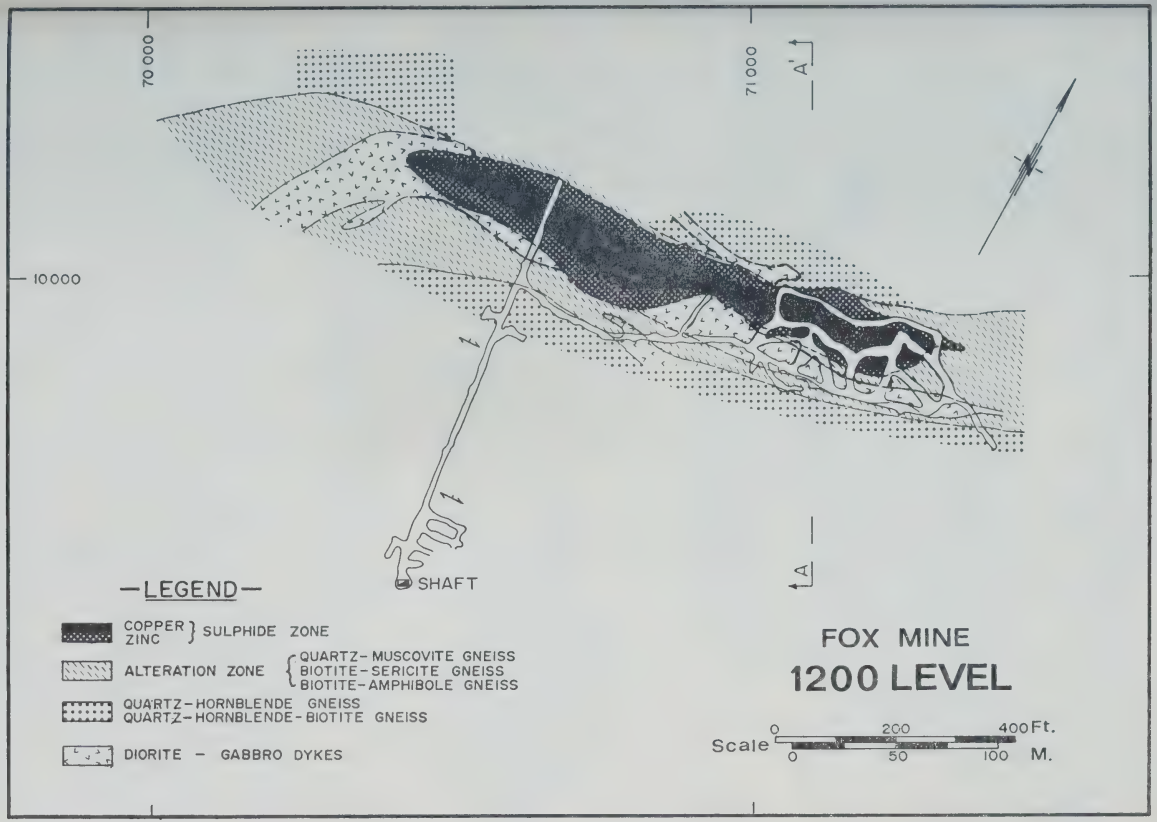

Fig. 14: Geological plan of the 1200 level, Fox Mine.

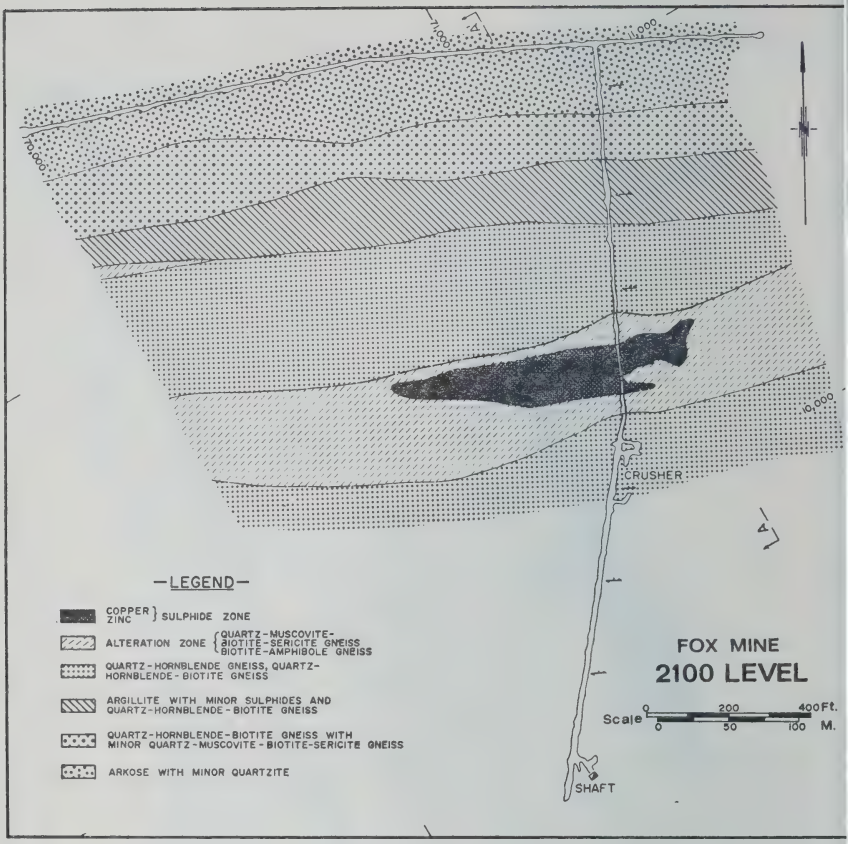

Fig. 15: Geological plan of the 2100 level, Fox Mine.

Mineralization

The ore zone is approximately 100 feet (30 m) wide, 1,500 feet (450 m) long and extends from surface to the 2850 foot (855 m) level. It contains two lenticular orebodies and is conformable with the enclosing rock units and regional gneissosity. Approximately 70 per cent of the ore zone is composed of massive sulphides with the remaining 30 per cent, disseminated sulphides. Contacts between massive sulphide and wallrock are relatively sharp. Massive sulphide ore consists of medium-grained granular pyrite with varying proportions of interstitial pyrrhotite, chalcopyrite, sphalerite, arsenopyrite and inclusions of quartz-feldspar gangue. In the

higher grade zinc sections of the ore zone, mineralogical banding or layering is evident in the massive ore. Successive bands are composed of sphalerite, pyrite and pyrrhotite or pyrite with silicate gangue minerals, which are conformable to the plane of the ore zone and the structure of the enclosing gneissic rocks.

Disseminated sulphide ore consists of the same sulphide assemblage that is present in massive ore, but contains a higher proportion of silicate minerals, especially biotite, amphibole and chlorite. Copper-rich disseminated ore occurs at the eastern extremity of the ore zone and at other localities both within and surrounding zones of massive sulphides. This type of ore consists of pyrrhotite, pyrite, chalcopyrite, sphalerite and arsenopyrite and includes the silicate minerals, biotite, muscovite, sericite, talc, amphibole, quartz and albite.

A coarse-grained and apparently late sulphide ore, consisting of pyrrhotite, pyrite, chalcopyrite, sphalerite and arsenopyrite is found cutting and replacing both the massive and disseminated ore types at a number of localities in the mine.

Non-economic sulphide mineralization is present in the band of slatey sediments lying 200 - 400 feet (60 - 120 m) north of the ore zone (Figure 12). This mineralization consists of pyrite and pyrrhotite with minor quantities of chalcopyrite and sphalerite and is of two ages. Fine-grained disseminated pyrite and pyrrhotite have a superimposed coarser grained assemblage of the same sulphides irregularly dispersed throughout, which has formed by replacement or metamorphic remobilization.

Vertical, horizontal and lateral zoning of copper, zinc and iron are evident within the ore zone. The distribution of copper and zinc is generally inversely proportional. Higher copper values occur in the core of the ore zone, at the eastern extremity and at the western mid-section. Higher zinc values are found along the hangingwall and footwall contacts and are concentrated on the western side of the copper zones. The copper grades increase with depth and the zinc grades decrease. There is a coincidence in the distribution of the zinc and iron with the diorite-gabbro dyke that occurs along the footwall of the ore zone. Higher zinc values appear opposite the narrowest widths of the dykes and vice versa. No such relationship is apparent for copper.

Minor quantities of gold and silver have a variable distribution in the ore zone. The higher gold and silver values are associated with the higher copper values and with quartz-

epidote veins commonly associated with the diorite-gabbro dykes. No gold or silver minerals have been recognized in the sulphide ore zone. Some native gold and silver tellurides (hessite?) have been found occurring with galena and arsenopyrite in the quartz-epidote veins.

The ore zone is enveloped by a hydrothermal alteration zone which in plan is approximately 250 feet (75 m) wide and 1800+ feet (540+ m) long and extends to below the 2850 level. The minerals present, in order of decreasing abundance, are quartz, muscovite, albite, sericite, biotite, amphibole, talc and chlorite. Many of the products of this hydrothermal alteration appear to be zonally distributed and exhibit a tendency to occur in mutually exclusive association regardless of host rock.

Ore Paragenesis

The Fox Mine ore zone appears to have had an epigenetic hydrothermal origin, subsequently modified by metamorphism. It is probable that there was an initial accumulation of fine-grained pyrite, which was subsequently recrystallized to a granoblastic texture by metamorphism. These fine-grained sulphides occur along the contact of the ore zone and they could be the remnants left after replacement. Preliminary microscopic studies of the sulphides indicate some preferred crystallographic orientations, porphyroblastic growth of the pyrite, brecciation and fracturing. Pyrrhotite occurs along the outer edges of the ore zones and may have been derived by metamorphism of the original pyrite with the release of sulphur. Evidence for an epigenetic origin for the ore is:

(a) The ore zone is surrounded by haloes of hydrothermal alteration which are symmetrical with the disposition of the chalcopyrite and sphalerite;

(b) The ore zone selectively replaces bands within the gneiss after the gneissic fabric has been destroyed with a felted mass of hydrothermal alteration products.

(c) The ore zone contains scattered fragments of the surrounding related wall rocks, and although the gneissosity of most of these retain a similar attitude to the gneissosity of the wall rocks, some are randomly orientated.

(d) The diorite-gabbro dykes, which are pre-folding in age, have been replaced by the ore zone, after losing their gneissosity in the alteration zone.

Geology of the Thompson Nickel Belt

Map 3 is a coloured geological map of the Thompson nickel belt at a scale of 1:100,000 outlining an area of approximately 1580 square miles (4100 sq. km). The map area stretches for 110 miles (176 km) along the regional strike of the belt, from the Odei River in the northeast to Manibridge Mine in the southwest. The map was compiled from geological maps of the International Nickel Company of Canada Ltd. and the Province of Manitoba, Department of Mines, Resources and Environmental Management. This data was supplemented by the authors' personal knowledge of the geology of the region. Additional geological information was obtained from Falconbridge Nickel Mines Ltd. and the Geological Survey of Canada. The map, in slightly different form, was originally published for a geological field trip to the Thompson nickel belt (Quirke, Cranstone, Bell and Coats, 1970).

The Thompson nickel belt includes rocks that have been assigned to the Pikwitonei province, the Wabowden subprovince (Churchill), and the undivided portion of the Churchill province. All the presently known nickel deposits of the Thompson nickel belt lie within the northeasterly-striking Wabowden subprovince. This subprovince is bounded on the northwest by the Churchill province. The origin and age of Wabowden subprovince rocks and the nature of the boundaries between the Wabowden subprovince and the Churchill and Pikwitonei provinces have proved a complex geological problem. This problem has been considered at various times by the following and by other authors: Bell (1964, 1966, 1971a, 1971b, 1971c), Gibb (1968), Gibb and Walcott (1970), Gill (1949), Kornik (1969), Kornick and MacLaren (1966), Patterson (1963), Quirke, et al. (1970), Rance (1966), Rousell (1965), Stockwell (1963, 1964), Stockwell, et al. (1965, 1969), Wilson and Brisbin (1961, 1962) and Wilson (1949 a, 1949 b).

Southwest of Thompson, the boundary between the undivided Churchill province members and the Wabowden subprovince units is a steeply dipping, cataclastic, fault zone (Setting Lake fault). This zone underlies portions of Setting Lake and Lower Ospwagan Lake, and can be traced between them. The Churchill province and Wabowden subprovince rocks that flank this shear zone have few lithologic similarities, so that the boundary in this area is well established. Northeast of Thompson, the fault zone swings more easterly and the lithologic differences between Churchill province and Wabowden subprovince rocks are not as clearly defined.

The boundary configuration between the Wabowden subprovince and the Pikwitonei Province is not completely understood. Northeast of Apussigamasi Lake, this boundary is a cataclastic fault zone that lies near to, and parallels, the Burntwood River. This fault is a branch of the Assean Lake fault (Haugh, 1969). At Apussigamasi Lake, the fault swings to the south, beneath Pleistocene overburden (Map 3, Figure 2). From here southwest, the nature of the extension of the Wabowden-Pikwitonei boundary is not known. Further southwest, in the vicinity of Partridge Crop Lake and Wintering Lake, there is no obvious evidence of faulting in the existing outcrops. Here the boundary has been complicated by the intrusion of two elongate granitic batholiths. Limited field and petrographic work at this locality and still further southwest, near the western end of Sipiwesk Lake leads Cranstone to tentatively suggest that the Wabowden subprovince migmatites, gneisses, and hornblende granulite facies equivalents may represent original Pikwitonei province rocks. These old rocks have been strongly metamorphosed and deformed. The resultant superimposed folds and foliation now strikes northeast, parallel to the Thompson nickel belt. This re-metamorphism is most likely to have occurred during the Hudsonian orogeny (1600 - 1700 million years ago) but there is no evidence yet to substantiate this. Such an origin for the Wabowden subprovince units is similar to that proposed by Rance (1966), who reached his conclusion through structural studies and petrographic evidence. Considerably more evidence is needed to prove this origin of the Wabowden subprovince.

Another possible origin for rocks of the Wabowden subprovince is that they may be high metamorphic grade paragneisses, that were not necessarily part of the Pikwitonei province. It has been suggested by Bell that they may represent either an authochthonous remnant that was sliced from the Archean rocks of the Flin Flon subprovince, a horst of Archean basement from beneath the Churchill province, or an Archean allochthon that was transported by gravity, northwest, off the Pikwitonei-Superior continent into an Aphebian sea (Bell, 1971 b). They might even be highly metamorphosed and metasomatized Aphebian rocks that are correlative with the supracrustal Churchill province units lying northwest of the Setting Lake fault.

Lithology

Descriptions of the various rock units on Map 3 are grouped by geological province and subprovince and hence are not in numerical order. Map unit 6, 8, and 12 are found both in the Wabowden subprovince and in the Churchill province. To avoid duplication they are described only once, under the Wabowden subprovince heading.

Pikwitonei Province

Rocks of the Pikwitonei province comprise a variety of hornblende granulite to pyroxene granulite facies gneisses, hypersthene granites (enderbite and charnockite), crudely layered mafic granulites, and their retrograded equivalents. These are mapped as *hypersthene granulites,* and *hypersthene granites (Map unit 13).* Although quartzo-feldspathic varieties predominate, most outcrops contain numerous blocks and lenses of the mafic granulites.

In the areas where they are exposed, the majority of the Pikwitonei province rocks belong to the plagioclase-clinopyroxene-orthopyroxene-quartz, plagioclase-clinopyroxene-orthopyroxene - garnet, plagioclase - hornblende - clinopyroxene-orthopyroxene, and plagioclase - clinopyroxene - orthopyroxene - hornblende - garnet subfacies of the pyroxene granulite and hornblende granulite facies. They can be stratiform gneisses, with parallel alternating layers of different composition, or foliated gneisses that have a parallel fabric caused by planar disposition of rock-forming minerals. In many areas they are massive and granitic. They are medium-grained, essentially granoblastic (some outcrops cataclastic) rocks, which in some areas are a honey brown colour, with a characteristic rusty friable weathering.

Retrogression of the orthopyroxene is extensive and most original orthopyroxene grains have been, partially to completely, altered to fine-grained pseudomorphs of secondary minerals. These alteration products consist of various assemblages of tremolite-actinolite, biotite, anthophyllite, serpentine, talc, chorite, epidote, leucoxene, calcite, phlogopite, magnetite, and quartz. Areas up to many square miles in extent may exhibit completely replaced orthopyroxene grains. In other areas, nearly all of the orthopyroxenes in one specimen from a particular outcrop may be completely fresh and unaltered, however a second specimen from the same outcrop may contain only pseudomorphs.

It has been suggested that the Pikwitonei province granulites are early Precambrian and represent the oldest rocks in the area (Bell 1971 a, 1971 c). Conclusive proof of this would be the discovery of pre-Kenoran radiometric ages from rocks in the Pikwitonei province. The search for the age of the Pikwitonei province is further complicated by an overprinting of the Kenoran and possibly the Hudsonian orogenies. Kenoran K-Ar age dates of 2400 and 2715 million years have been obtained for granulite specimens from the Pikwitonei province.

Churchill Province (Wabowden Subprovince)

The major portion of the Wabowden subprovince consists of a complex of migmatites and granoblastic gneisses that are grouped as *migmatites, granoblastic gneisses and granulites (Map unit 7)*. Typical Wabowden subprovince migmatites are fine- to medium-grained, and contain an average of 70 per cent biotitic gneiss paleosome fraction, 25 per cent quartzo-feldspathic leucosome, and 5, or more, per cent dark grey to almost black, plagioclase amphibolite. The amphibolite occurs as lenses and blocks, and remnant tabular and boudinaged layers. Most amphibolite remnants are a few inches to several feet across. The gneisses and the paleosome fraction of the migmatite generally have well developed compositional layering. Light grey feldspathic layers alternate with relatively thin dark grey layers in many outcrops, and on the fresh surface, rocks are light to medium and rarely dark grey. These rocks weather light grey to buff.

The migmatite is extremely permeated by granitic leucosome. This fraction comprises a complex network of small irregular masses, dykes, sills, sheets, tongues and laminae. In some areas, extensive metasomatism has destroyed the original layering in the migmatites to the point where cursory examination suggests a plutonic granite. Some outcrops are granoblastic gneiss, cut by a late quartz monzonite stockwork, or a migmatitic complex that is extensively permeated by granitic leucosome and granitic magma. Cataclastic textures such as strong undulose extinction in quartz, microbrecciation, mortar structures, and flaser textures are common in the rocks from map unit 7.

In that part of the Wabowden subprovince between Paint Lake and Brostrom Lake, many unit 7 gneisses contain garnets, and less commonly cordierite and sillimanite. These rocks are probably metasediments.

Although most unit 7 members are amphibolite facies, many rocks in the area between Paint Lake and Brostrom Lake contain abundant orthopyroxene and are hornblende granulite facies. Orthopyroxenes from Wabowden subprovince granulites are almost invariably fresh and unaltered and therefore unlike the retrograded orthopyroxenes from the Pikwitonei province. This fact suggests that the Wabowden subprovince migmatites and granulites were formed during the Hudsonian orogeny (1600 - 1700 million years ago) and therefore are younger than the Pikwitonei province granulites (> 2,700 m.y.). This hypothesis explains why re-metamorphism and retrogression of orthopyroxenes in the Wabowden subprovince has not occurred during a latter metamorphic event.

The informal name *Thompson belt sediments (Map unit 5)* has been applied to the sedimentary and metasedimentary rocks which outcrop in a 4 mile (6.4 km) wide zone that lies between Moak Lake in the northeast and Setting Lake in the southwest. The dominant sediment is a fine-grained feldspathic quartzite or quartz-rich arkose. The map unit also includes variable amounts of diopside-phlogopite-carbonate rock (called "skarn" by geologists of the International Nickel Company of Canada), garnet - amphibole - magnetite - pyrrhotite-quartz rock that could be a metamorphosed iron formation, and in the vicinity of Ospwagan Lake, mafic tuffaceous rocks that are interbedded with thin layers of quartz-rich sediment that could be recrystallized chert. This possible recrystallized chert is similar to many of the feldspathic quartzites.

Map unit 5 also includes an unknown amount of mylonitized migmatites, mylonitized gneisses, and mylonitized sediments. Some of these cataclastic layers are many hundreds of feet thick. Mapping of these layers is hindered by limited outcrop, by the presence of many rocks of definite sedimentary origin in and around the cataclastic zones, and by difficulties encountered in identifying all the gradations from non-mylonitized sediments, through mylonitized sediments, mylonitized gneisses, mylonitized migmatites, flaser gneisses and flaser migmatites.

The contact between the sediments of map 5 and the gneisses and migmatites of map unit 7 is exposed only in a very few localities. One such exposure is in the Thompson Mine, another at Lower Ospwagan Lake. At these localities, the contact is relatively abrupt, and the sediments appear to be more or less conformable with the enclosing gneisses and

migmatites. As there is very little evidence to suggest that the gneisses and migmatites formed by metamorphism of the sediments, the relationship between the two rock types and the history of their origin is still conjectural.

The Moak, Mystery, Thompson, Birchtree and Pipe nickel deposits all occur within, or immediately adjacent to, sedimentary rocks of map unit 5. Many of the serpentinites and serpentinized periodotites are also enclosed by these sediments.

Mafic volcanic rocks (Map unit 6) are found at Upper and Lower Ospwagan Lakes. These are predominantly fine-grained, dark green mafic flows. Individual flows range from a few feet (1 m) to several tens of feet (10 - 30 m) thick. Deformed pillow lavas are common, and mafic tuffaceous sediments occur in some areas. Certain tremolite-actinolite and antigorite members could conceivably have been ultramafic flows. More probably, however, they have formed by alteration of the ultramafic intrusive rocks of map unit 11. Some of the volcanics have been metamorphosed to fine-grained amphibolites.

At Mystery Lake, somewhat similar mafic rocks are also probably volcanic, however they could be altered peridotite that was formed by alteration of the large serpentinized peridotite body that underlies the lake. Other mafic volcanic rocks outcrop near the north end of Setting Lake. These lie on the Churchill province side of the boundary. They are predominantly mafic tuffaceous sediments with some interbedded mafic lavas. With increased metamorphism they are altered to the amphibolites of map unit 8.

The majority of the *amphibolites (Map unit 8)* occur as elongate lenses and layers that parallel the regional foliation. The identical amphibolites of the Churchill province have also been included in map unit 8. Most of these rocks are fine-grained, and range from massive and gneissic plagioclase amphibolites to less common, hornblende plagioclase schists. Many of the amphibolites probably represent metamorphosed volcanic lavas, tuffs and/or volcaniclastic sediments. Some of those found in the Wabowden subprovince may represent retrograded mafic granulites that were originally part of the Pikwitonei province. They would have been altered during the Hudsonian orogeny.

The rocks assigned to *granodiorite and porphyritic granodiorite (Map unit 9)* range from leucocratic granodiorite to leucocratic quartz monzonite. They are mostly grey-white and they range from medium- to coarse-grained. Much

coarser pegmatitic phases occur southeast of Soab Lake, and at the northeast end of Lower Ospwagan Lake.

A large body of grey-white to pale buff-grey granodiorite extends from the city of Thompson northeast to the north end of Mystery Lake. This granodiorite constitutes the major portion of map unit 9. It commonly has a porphyritic texture, with phenocrysts deformed by cataclasis in many outcrops to yield augen-shaped grains. The southeast contact of this body appears to be a cataclastic fault zone at Mystery Lake. Further southwest, however, on the Burntwood River near Thompson, identical granodiorite clearly intrudes, and is younger than, slaty quartzose sediments of map unit 5.

The leucocratic granodiorites (map unit 9) in the central and northeastern portions of Setting Lake are fault-bounded wedges, caught up in zones of mylonites and other cataclastic rocks.

Two bodies of *hornblende-quartz monzonite (Map unit 10)* occur southwest of Wabowden and south of Halfway Lake. The first is about 40 square miles (104 sq. km) in area, the other about 10 square miles (25 sq. km). The typical hornblende-quartz monzonite is homogeneous, medium grained and medium grey, and has a faint to moderately well developed foliation. Composition ranges from hornblende granodiorite to hornblende-quartz monzonite, with some rocks having a sufficiently low quartz content to be classified as monzonite. In many outcrops, hornblende-quartz monzonite is extensively cut by small *lit-par-lit* injections and irregular dykes of younger, orange-pink, granitic and pegmatitic material. The hornblende-quartz monzonite is perhaps syntectonic but probably pretectonic to the Hudsonian orogeny. Cataclastic features (strong undulose extinction in quartz, microbrecciation, mortar structures and flaser textures) are evident in nearly all the thin sections studied. These cataclastic textures, as well as those observed in rocks of map units 7 and 9 are presumably related to the period of major faulting that produced the Moak Lake-Setting Lake fault zone and related faults.

The *ultramafic rocks (Map unit 11)* are chiefly serpentinized peridotite and serpentinite. Several hundred ultramafic bodies of substantial size, larger than 100 feet (30 m) thick and 1000 feet (300 m) long, and countless smaller bodies, are known to occur along the entire length of the Thompson nickel belt. They are associated with a linear gravity

low and the major Moak Lake-Setting Lake cataclastic fault zone. Only two or three outcrops of these ultramafic rocks are known along the nickel belt, the largest and most notable being the surface showing at the Mystery Lake nickel deposit. Most of the ultramafic bodies have been located by geophysical exploration and subsequent diamond drilling. Some are tabular and may have remained *in situ* after having formed as sill-like bodies, although others appear to have migrated along the faults and shear zones to their present positions. A number of bodies contain disseminated pyrrhotite and pentlandite, and some of the sulphide-bearing bodies contain sufficient nickel to constitute nickel ore, or submarginal nickel deposits.

Only the principal ultramafic bodies known in the area are plotted on Map 3. Of the remainder, most occur in the Wabowden subprovince with a few in the undifferentiated Churchill province, as discordant tabular bodies within cataclastic zones and as concordant bodies within folded gneisses and migmatites.

A detailed study of the ultramafic rocks of the Thompson nickel belt was made by Coats (1966, 1968), and the interested reader is referred to these references for additional data.

Gabbro and diabase dykes (Map unit 12) strike northwest and appear to represent the latest igneous activity in the area. They post-date the Hudsonian orogeny (1600 -1700 m.y. ago) and the Moak Lake-Setting Lake fault zone. The rocks are fresh and unmetamorphosed, and exhibit fine-grained, chilled, contacts with the enclosing rocks. These dykes belong to the northwest-trending Mackenzie dyke swarm, for which K-Ar ages of 865 m.y., 1095 m.y., 1105 m.y. and 1130 m.y. have been obtained elsewhere in Manitoba.

Churchill Province

Metasedimentary rocks and paragneisses (Map unit 1) are the major components of that part of the Churchill province lying northwest of the Moak Lake-Setting Lake fault zone. The least metamorphosed of these sediments occur along the northwest shore of Setting Lake. There, the rocks are fine-grained, relatively unmetamorphosed (biotite zone), quartzofeldspathic, semi-peltitic and psammitic sediments that are fine-grained, medium to dark grey in colour, and vary from non-bedded to well-bedded. Individual beds range from a fraction of an inch (1 cm) to several feet (1 to 2 m) thick. Northwest of Setting Lake, metasediments contain scattered pebbles and local interbeds of conglomerate.

The majority of rocks included in map unit 1 are higher-grade garnetiferous paragneisses and migmatites that were derived from sediments. These rocks are composed of plagioclase, quartz, biotite, garnet, magnetite, (± microcline), and commonly sillimanite and/or cordierite. They are characterized by abundant mauve garnets and from 10 to 20 per cent or more, of a characteristically white granitic mobilisate or neosome fraction. These rocks are identical in mineralogy, texture and appearance to the metamorphosed Wasekwan Group rocks of the Lynn Lake-Southern Indian Lake district, and to the Nokomis Group paragneisses and migmatites of the Snow Lake area. All these rocks have a probable common origin, and it has been hypothesized by Bell (1971c) that they belong to the super group that makes up the Circum-Ungava geosyncline.

Granitoid paragneiss, porphyroblastic gneiss, and gneissic augen quartz monzonite (Map unit 2). The granitoid paragneiss and gneissic augen quartz monzonite occur northwest of Pakwa Lake and on islands in this lake. The porphyroblastic gneiss occurs only between Pakwa Lake and Setting and Kiski Lakes. The gneissic augen quartz monzonite and porphyroblastic gneiss may have formed by recrystallization, and potash metasomatism, of an original layered quartzo-feldspathic sedimentary rock.

The granitoid paragneiss is layered and apparently formed by granitization of bedded, quartzo-feldspathic sediments. Many outcrops could be described as *lit-par-lit* gneiss, with orange-pink granitic layers up to a few inches (6 cm) thick. In many outcrops granitoid paragneiss and gneissic augen quartz monzonite are interlayered, with sharp boundaries, but elsewhere they are gradational both along and across strike.

The typical porphyroblastic gneiss consists of a medium-grained, medium- to dark-grey, foliated matrix (plagioclase, quartz, biotite and/or hornblende, and microcline) containing up to 20 per cent pale grey-orange microcline porphyroblasts. The porphyroblasts are tabular with most being greater than 2.5 cm in maximum dimension. They contain numerous small, relict, inclusions of the matrix minerals. Either potash metasomatism, or redistribution of potash feldspar in the original rock could plausibly explain the formation of the porphyroblasts.

Quartz monzonite and granodiorite (Map unit 3). The dominant rock type of this unit is a medium- to coarse-grain-

ed quartz monzonite to granodiorite. These rocks range from massive to weakly foliated, and contain an average of about five per cent biotite. They were formed during the Hudsonian orogeny. No sharp boundary can be delineated between the granitic rocks of map unit 3 and the probable potassium metasomatic rocks of map unit 2.

A complex of older rocks that are extensively veined by granitic rocks of variable composition and colour, and which can be described as agmatite constitutes the *agmatite and related rocks (Map unit 4)*. At Kiski Lake, the veined fraction of the agmatite consists predominantly of weakly foliated, medium-grained, medium to dark grey, hornblende-biotite-quartz diorite. At Setting Lake, the relict inclusions consist mostly of amphibolite (unit 8), garnetiferous paragneiss (unit 1), and gneissic biotite granodiorite. Near the southern end of Setting Lake, some of the areas mapped as agmatite and related rocks are chiefly homogeneous 'granite' with very few inclusions of older rocks.

Northwest of Soab Lake and Joey Lake, two separate bodies of mixed rocks consist of relict, mafic, septa and schlieren of sediments and gneisses, and interlayered, younger, pink granite or mobilisate fraction. As these bodies of migmatite are completely engulfed by granitic rocks of map unit 3, they have been grouped with the agmatites (map unit 4).

Structural Geology

The structural geology of the area is complex and not as yet thoroughly understood, because of sparsely distributed outcrops, lack of distinctive marker horizons, and extensive faulting parallel, and sub-parallel, to the regional foliation.

The Wabowden subprovince is characterized by northeast-trending structures and a parallel, steeply dipping, regional foliation. The entire 'belt' cuts across the regional east-west structural trend that prevails throughout the rest of the Precambrian of Manitoba. The 'belt' rocks dip steeply and have a pronounced northeast strike. Most of the folds consist of elongate isoclinal domes and basins, with near vertical, northeast-striking axial planes.

The Pikwitonei province is characterized by an east- and northeast-striking regional foliation that dips steeply. East of Thompson the rocks strike east, but those east of Wabowden strike more to the northeast. The folding style is not known.

The Churchill province rocks, that appear on Map 3, also have pronounced northeast structural trends. Folds become more open, strike varies considerably and dips are flatter, as one proceeds northwest, away from the Wabowden subprovince.

Mineral Deposits

All presently known nickel deposits of the Thompson nickel belt occur within the Wabowden subprovince, in an approximately linear zone, which lies no more than 3 miles (4.8 km) from the northwest boundary of the subprovince. Some nickel deposits consist chiefly of disseminated pyrrhotite and pentlandite, with lesser pyrite and chalcopyrite, in ultramafic rocks. Examples are the Moak and Mystery deposits, a small portion of the ore in the Thompson Mine, Pipe #2 Mine, Soab North Mine, the Bowden and Bucko deposits, and the Manibridge Mine.

A second group of deposits consist of relatively massive sulphide bodies which consist of pyrrhotite-pentlandite, with lesser pyrite and chalcopyrite. The massive sulphides commonly contain numerous wallrock inclusions. Sulphides are chiefly fine-grained, and occur in gneisses and sediments of the Wabowden subprovince. Sulphides contain scattered ultramafic rock inclusions which range in size from very small to several metres across, but the volume of ultramafic rock is small relative to the amount of sulphide. Hence, in this group of massive sulphide deposits, the small volume of ultramafic rocks in each deposit cannot have been the source of the sulphide. Nevertheless, it seems likely that both the disseminated sulphide deposits and the massive sulphide deposits have a common genesis. Examples of deposits consisting of relatively massive sulphides in gneisses and/or sediments are the Thompson, Birchtree, and Soab South Mines.

A relationship seems to exist between cataclastic and other fault zones, ultramafic rocks, and nickel deposits. Many of the ultramafic bodies occur within or close to cataclastic or other fault zones, and some are enclosed, at least in part, by cataclastic rocks. Examples of nickel deposits with such a relationship to cataclastic fault zones are the Moak and Mystery deposits, Birchtree Mine, Bowden deposit, and the Manibridge Mine. The geology of the Thompson, Moak, Pipe #2 (open pit), Soab North and Manibridge Mines is described below.

Thompson Mine

At the time production started at the Thompson Mine in 1960, the proven ore reserves amounted to 25,000,000 tons containing 2.97 per cent nickel plus copper (Zurbrigg, 1963, p. 451). Through the years since 1960, these reserves have been essentially maintained. In The International Nickel Company prospectus for March 1968 (p. 7), which gives the latest published figures, proven ore reserves for Manitoba were listed as 67,313,000 tons, with a nickel content of 1,270,000 tons (1.89%) and a copper content of 90,000 tons (0.13%). From the same source, the tonnage mined in Manitoba during 1967 was 1,976,000, grading 2.77% nickel and 0.18% copper. The INCO 1969 Annual Report (pp. 7 and 8) gives the approximate daily production from the Thompson Mine during 1969 as 8,000 tons per day, and from the Birchtree Mine as 4,000 tons per day.

*Geology**

The major structure that controls the distribution of ore at Thompson is an anticlinal fold striking northeast and plunging steeply to the south. The locus of the ore is a schist zone which is continuous over the length of the structure and which is conformable with the overlying and underlying formations. The ore zone has an over-all length of 3.5 miles (5.6 km). The main concentration of ore occurs along the southern portion of the east limb of the fold, around the nose of the fold and within associated minor crenulations and drags.

A plan and section illustrating the geological features of the south part of the mine are shown in Figures 16 and 17. The location of the plan with respect to the larger structure is indicated in Figure 18 by the rectangular outline south of Thompson Lake.

The rocks that define the folding in the mine consist of conformable gneisses, metamorphosed sediments, serpentinized peridotite and pegmatite. There is no evidence of an unconformity between the gneisses and the metamorphosed sediments. If quartzite, by virtue of its position in the core of the anticline, is the oldest unit in the sequence, then the granitic gneisses overlie the metamorphosed sediments. The assumption that recognizable sediments are roots of downfolds of younger rocks in an older crystalline basement, is

*From Zurbrigg (1963), with minor modifications.

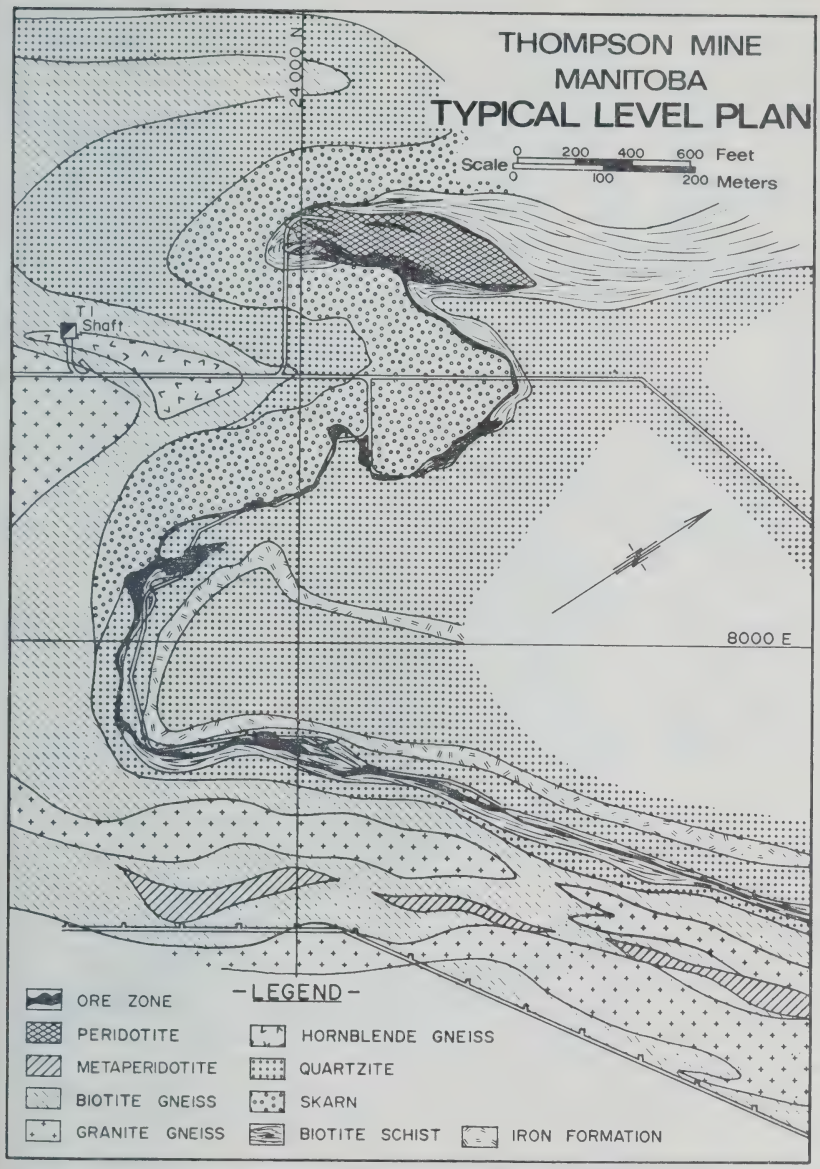

Fig. 16: Geological plan of typical level, Thompson Mine.

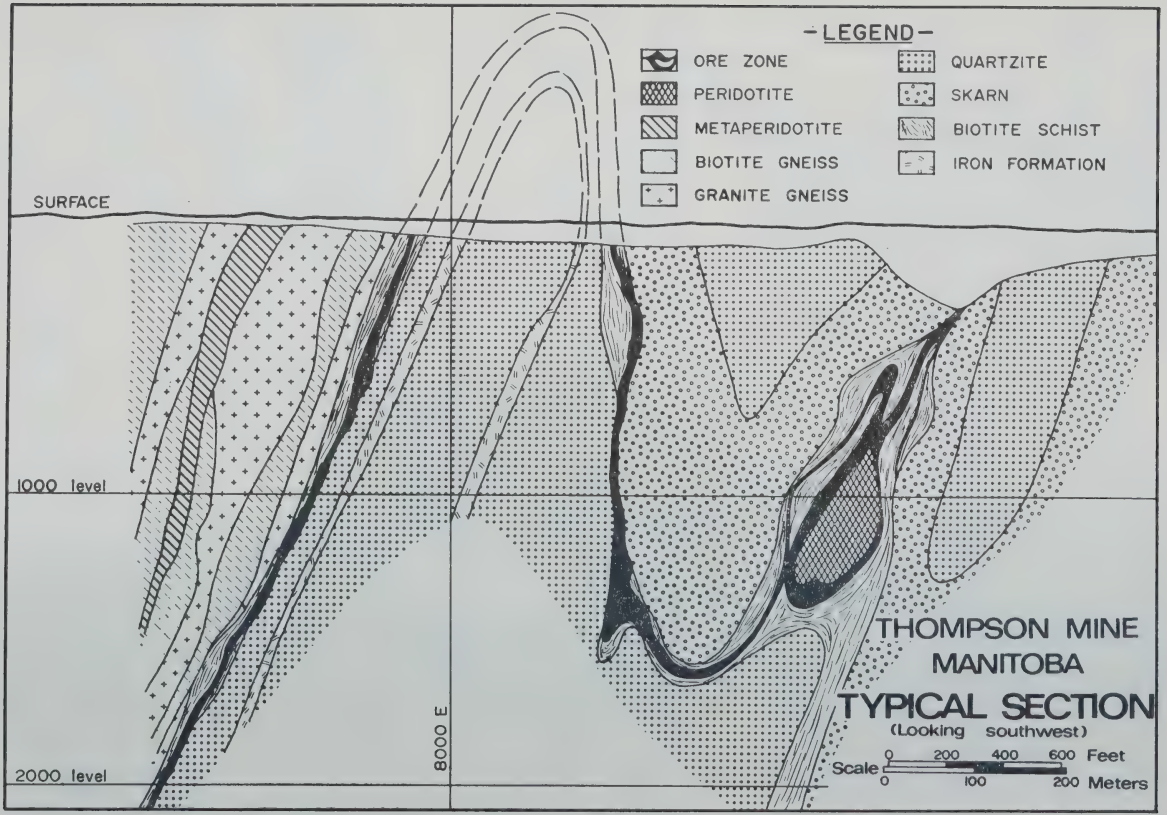

Fig. 17: Geological section, looking southwest, Thompson Mine.

therefore not borne out by structural or stratigraphic evidence at the Thompson Mine.

The *quartzite* in the core of the fold is massive and coarse-grained, and has a variable microcline, plagioclase, biotite, muscovite, zircon, apatite and sphene content. It grades into the adjacent rock types.

The typical *skarn* is massive to thinly banded, light green, medium to coarse-grained, and contains prominent coarse diopside and silky phlogopite. Common mineral assemblages are carbonate-diopside, carbonate phlogopite-diopside, diopside-clinozoisite, are carbonate-diopside-tremolite-microcline. All of these assemblages occur within the range of stability of the amphibolite facies of regional metamorphism.

The *iron formation* is commonly banded. The dark bands are composed of garnet, amphibole, carbonate, biotite, pyrrhotite and magnetite in varying proportions; the light bands consist of coarsely crystalline quartz. In some places, the banding is sharp; in others, it is almost obliterated by the development of coarse garnet, amphibole and pyroxene.

The *biotite schist* comprises a dark to pale brown, medium- to fine-grained, drag-folded horizon, composed of biotite, quartz, plagioclase, orthoclase, chlorite, white mica, garnet and sillimanite. It is characterized by very thin, alternating, biotite-rich and quartz-feldspar-rich bands, with occasional wider bands of coarse quartz-feldspar material that resembles pegmatite. The effects of retrograde metamorphism are widespread in the schist zone. The above rocks are grouped in map-unit 5 of Map 3.

The *biotite gneiss* is light, to dark, grey and has prominent bands of biotite. It is composed of quartz, plagioclase and biotite, with or without microcline, muscovite and sillimanite. Granite gneiss is distinguished from biotite gneiss on the basis of its pink colour and discontinuous foliation. Narrow mica-rich bands are separated by wider zones consisting of plagioclase, orthoclase, quartz and mica. These two rock-types are grouped in map-unit 7. The amphibole gneiss is commonly a medium-grained, massive to weakly foliated aggregate of equigranular hornblende, plagioclase, quartz, biotite and garnet, with accessory magnetite, ilmenite, apatite, zircon, sphene and sulphides. This is shown as map-unit 8.

The larger cross-cutting masses of *pegmatite* are made up of fresh coarse aggregates of quartz, orthoclase, sodic plagioclase, coarse biotite and minor muscovite. Finer grained

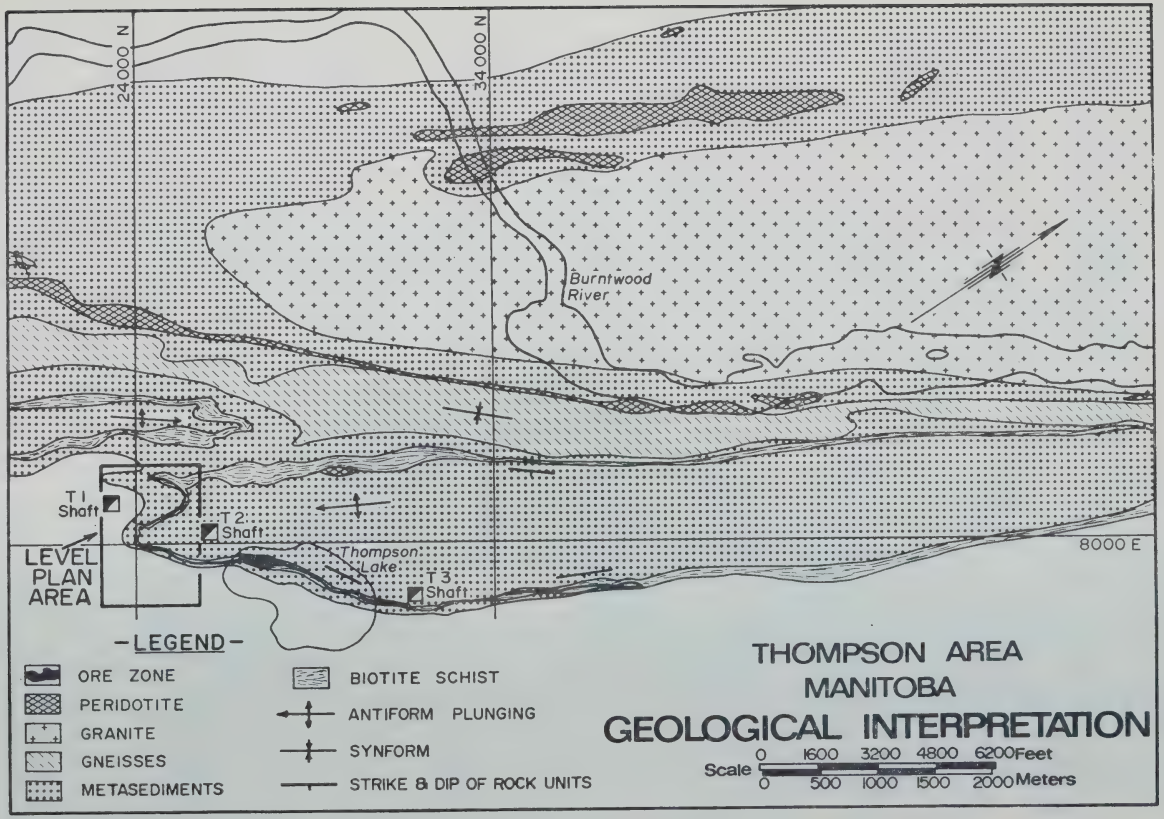

Fig. 18: Interpreted geological plan, Thompson area.

material of similar composition occurs as narrow concordant bands in the schist zone.

The typical *peridotite* is composed of pseudomorphs of serpentine after olivine and pyroxene. Where the rock is not sheared, the nature of the original texture is indicated by the distribution of fine-grained magnetite, one of the breakdown products of the original olivine, and by the rare occurrence of unaltered olivine and pyroxene. The metaperidotite is made up of orthopyroxene, magnesian amphibole, olivine, clinochlore and green spinel. It may have developed from serpentinized peridotite by progressive metamorphism. These rocks are included in map-unit 11.

Mineralization

The ore is composed of pyrrhotite, pentlandite and pyrite, with minor chalcopyrite and marcasite and trace amounts of nickel arsenides. The paragenetic relationships indicate the early formation of pyrite, with minor pyrrhotite, chalcopyrite and graphite, followed by crystallization of the nickel minerals, including the bulk of the pyrrhotite. Marcasite-carbonate veinlets and graphite-lined fractures cut the ore. Near the surface, some of the pyrrhotite has altered to pyrite and magnetite and some of the pentlandite to violarite and magnetite.

The sulphides occur as fine-grained masses, lenses and veinlets in the schist, as coarse-grained masses and stringers where the host rock is less schistose, and as stringers, veinlets and disseminations in peridotite. Both the coarse-grained and the fine-grained sulphide masses are termed breccia sulphide, in recognition of the numerous rock inclusions or remnants contained in them. The remnants range in size from mere specks to several inches in diameter, and, particularly in the fine-grained breccia sulphide, they have extremely irregular contacts with the country rock.

K-Ar Dates

In 1968, Wanless, et al., reported K-Ar dates from samples collected by Quirke and Bell (GSC numbers 66-100, -101, -102, -103, -104). One of these was from biotite within breccia sulphide ore, two from mica in pegmatite associated with ore, and the fourth from at least 800 feet (240 m) out into the hanging-wall gneiss (unit 7, map 3). 'Dates from these rocks range from 1515 $\pm$ 50 to 1630 $\pm$ 50 m.y. and indicate that they are some of the youngest Precambrian rocks from Manitoba to be dated by the Geological Survey of Canada.

Although it may be that the age differences of the rocks are significant, it would seem safer at this point to assume that only the general date of the most recent metamorphism has been measured. Certainly, the 1515 ± 50 m.y. from the hanging-wall gneisses (GSC 66-103) is the date of regional metamorphism and thus it should follow that the other associated rocks have been at least modified by what might have been the final throes of the Hudsonian orogeny' (Wanless et al., 1968, pages 87-88.).

Within the immediate mine area, the country rock metasediments and paragneisses are intruded by locally derived pegmatites. The ore deposition appears to be post-pegmatite. The biotite from this pegmatite (GSC 66-101) dates at 1590 ± 50 m.y. Biotite enclosed by ore (GSC 66-100) dates at 1515 ± m.y. Muscovite-rich selvage at the pegmatite-ore contact (GSC 66-102) dates at 1630 + 50 m.y. The hanging-wall country rock (a feldspar-quartz-biotite paragneiss, GSC 66-104) date of 1515 ± 50 m.y. indicates the time of regional metamorphism. These four dates are younger than the mean of 1735 m.y. for the Hudsonian orogeny (Wanless, and others, 1967). Although these associated 'young' dates at the Thompson Mine may be significant, it is more probable that they again indicate the final pulses of the Hudsonian orogeny metamorphism. Comparable 'young' dates from nearby parts of the Churchill Province in Manitoba are GSC 60-75, 61-120, 63-106 and 63-107 (Wanless, et al., 1968, page 88).

Ore Paragenesis

The following observations, made in the course of drilling and mapping underground, are considered by the Mines Exploration personnel of the International Nickel Company of Canada Limited to bear on the genesis of the Thompson ore:

1. The volume of sulphide is high compared to the volume of peridotite and it is therefore felt that the peridotite that has been observed underground cannot have been the sole source of the sulphide.
2. Only background amounts of nickel are present in certain of the Thompson peridotite bodies while others are of ore grade. There is the possibility that enrichment of the peridotites occurred after their emplacement.
3. The sulphide and peridotite bodies are emplaced along a zone of structural weakness which separates massive (unsheared) hanging-wall gneiss from more competent footwall quartzite. The zone of weakness now marked by

micaceous schist and sheared metasediments, developed prior to the emplacement of the sulphide and peridotite.

4. There are prominent concentrations of sulphide in dilatant zones that appear to be related in time to post-peridotite deformation and minor folding. The sulphides penetrated, and possibly replaced, at least some of each of the rock types in the ore zone, and stoped off, and transported, blocks of wall rock. Possible explanations for these relationships would include either remobilization of the initially emplaced sulphides by later metamorphism, later injection of sulphides from depth, or a combination of both mechanisms.

5. Following the last phase of sulphide crystallization there has been little observable deformation other than minor fracturing and faulting and some reworking of the shears associated with ore contacts.

Although these observations refer specifically to the Thompson Mine, it would appear that the sulphide in the Birchtree Mine has had a similar history. The much larger bodies of peridotite with disseminated sulphide, typified by that of the Pipe pit, may well reflect a closer relationship between sulphide and host rock than is evident at Thompson. Certainly there are localities in some of these peridotites where the existence of a magmatic sulphide phase has been recognized. The sulphide mineralization in such bodies may be a combination of an original magmatic sulphide and a later sulphide enrichment.

Moak Mine

The Moak Mine of The International Nickel Company of Canada is situated 17 miles (27 km) northeast of Thompson, and is the most northerly underground development on the Thompson nickel belt. Underground exploration was carried out on the Moak deposit to further explore nickel mineralization associated with a serpentinized peridotite body, which had been intersected by surface drilling. This ultramafic body is one of several which occur in the area. It is considered that a series of sub-parallel faults controls their distribution.

The serpentinite body which contains nickel mineralization has the form of a syncline, approximately concordant with the enveloping sediments. Sulphide content of this body has been shown to be extremely variable, ranging from scat-

tered disseminations with only background nickel values to massive sulphide zones many feet thick.

Serpentinite, sulphides and mylonitized gneissic rocks can be observed in the waste dumps on the west side of the headframe.

Pipe Mine

Development of the Pipe Mine open pit, situated close to Upper Ospwagan Lake, approximately 20 miles (32 km) southwest of Thompson, commenced with the removal of 12.6 million yards of overburden (9.4 million m^3). Following this, rock removal started in 1969 and the outline of the pit was established. Its dimensions are 2200 feet (660 m) long, 1600 feet (480 m) wide and it will have a final depth of 720 feet (216 m).

The orebody is confined to a serpentinized peridotite body occurring on the west limb of a deformed fold (Figure 19). The plunge of this fold is nearly vertical in all places, the direction being to the north or to the south.

Nickeliferous sulphides occur in several forms within the peridotite. Most widespread is disseminated sulphide, which consists of small specks and blebs of pyrrhotite, pentlandite and minor amounts of violarite either enclosed in serpentine pseudomorphs after olivine and pyroxene or interstitial to these pseudomorphs. The percentage of sulphide varies widely in different localities. The silicate component of this type is essentially serpentine (largely antigorite with varying amounts of chrysotile) and there are very few recorded instances of unaltered olivine or pyroxene.

The second major form of sulphide occurrence is in the form of stringers with a distribution that is strongly influenced by a pattern of sub-parallel shears. These stringers consist of massive sulphide and are particularly well developed on the west side of the pit. Although largely contained within the ultramafic rock, there is one stringer that can be traced from the south end of the orebody into the hanging wall on the east side. These stringers range from microscopic dimensions to many feet in width and their mineralogy is essentially similar to that of the disseminated sulphides. They are composed essentially of pyrrhotite, pentlandite and pyrite. Frequently the pentlandite is partially altered to violarite. Carbonate is commonly associated with the stringers and they also frequently contain euhedral crystals of magnetite.

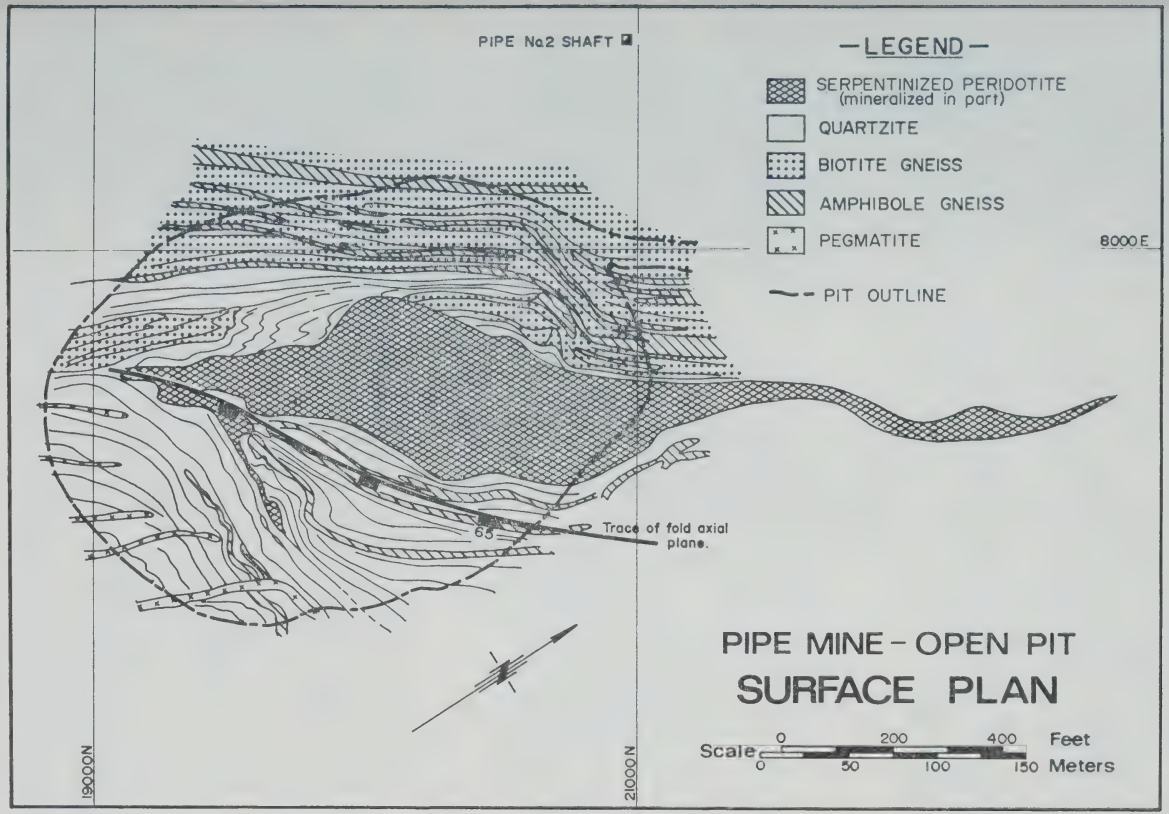

Fig. 19: Geological plan of the Pipe Mine open pit.

The metasediments which enclose the serpentinized peridotite are complexly folded and refolded on steeply plunging axes. The most common rock type is quartzite that contains varying amounts of biotite and some interbedded iron formations and calcareous sediments that are locally called skarns. Deformed amphibolites are important locally, and on the west side of the pit, more massive, biotite gneisses are in contact with the serpentinite. Local shearing has influenced the distribution of the sulphide stringers in the orebody and has also caused mylonitization of the principal country rocks. This shearing has taken place at low angles to the regional foliation.

Soab North Mine

The Soab North Mine is located 42 miles (67 km) southwest of Thompson, in an area of sulphide mineralization within a sequence of steeply dipping metasediments. The principal wall rocks are biotite gneiss, schists and pegmatites, with calcareous sediments and amphibolites achieving local importance. Three distinct horizons of mineralization occur within this sequence and parts of each have mineable concentrations of nickel sulphides. The ore is variously massive sulphide, mineralized schist, mineralized pegmatite or mineralized peridotite. The sulphide mineralogy is essentially similar to the other mines in the belt. The orezones are steeply dipping with little associated folding.

Manibridge Mine

Geology

The Manibridge mine of Falconbridge Nickel Mines Limited is located 80 miles (128 km) southwest of Thompson and 20 miles (32 km) southwest of the town of Wabowden. Production began in September 1971, with ore reserves of 1,409,000 tons grading 2.55% Ni and 0.27% Cu. The geological setting of this deposit is outlined by Coats and Brummer (1971).

Rock exposures in the vicinity of the mine shaft are composed of well foliated and often finely banded feldspar amphibole gneisses interlayered with zones of amphibolite and biotite granite gneiss. Augeniferous granite gneiss is conspicuous in some outcrops. Abundant coarse-grained pink granite pegmatite is visible in all outcrops as dykes and veinlets of varying widths, both cross-cutting and parallel to the gneissic foliation. In some localities pegmatite occurs as diffuse masses enclosing remnant fragments of amphibole gneiss and amphibolite.

Rock foliation strikes N30E and dips southeast between 60 - 80° with an average of about 70°. However, highly contorted and drag-folded foliation can be seen in outcrops adjacent to zones of faulting. This is accompanied by partial granulation or mylonitization of the rocks and the appearance of distinctive hematite staining and epidotization. A faint cataclastic foliation develops in the pegmatites at these localities.

Major faults have been intersected in exploratory diamond drill holes from both surface and underground. They are essentially strike faults, which appear to bifurcate and rejoin at intervals. The strong fault zone which occurs in the footwall rocks of the Manibridge ultramafic body, is a zone of mylonite up to 50 feet (15 m) in width. Within this zone there is a variation in intensity of mylonitization and contacts are gradational. Some evidence of cataclastic deformation is present in all rocks however, and such features as brecciated mylonites, mylonitized and fractured pegmatites indicate a long and complex history of dynamic metamorphism.

The *ultramafic intrusion* and host rock to the nickel sulphide ore at Manibridge is a conformable, linear body dipping southeast parallel to the enclosing rocks. Although the area is flat and muskeg covered between the widely scattered outcrops, the bedrock topography has a relief of about 300 feet (90 m). A steep walled bedrock depression up to 260 feet (78 m) in depth and filled with fine silt, clay sand and gravel layers follows the suboutcrop of the more easily eroded ultramafic rock. A geological plan of the second level and related cross section illustrate the principal features of the mine (Figures 20 and 21).

The ultramafic rock is a massive dark green to greenish-black serpentinite that generally shows textural patterns pseudomorphic after olivine and pyroxene. In some areas serpentinization has not proceeded to completion and primary silicate minerals olivine, pyroxene and amphibole are recognized. The amphibole is considered to be a primary silicate which crystallized in the more pyroxenitic phases of the ultramafic body and survived serpentinization to a greater degree than olivine or pyroxene. Both pyroxene and amphibole show euhedral crystal outlines in contact with sulphides and in rare instances, unserpentinized amphibole and partially serpentinized pyroxene are immersed in a sulphide matrix. Primary rock types indicated by pseudomorphs and remnant primary silicates are peridotite and minor amounts of amphibole-bearing olivine pyroxenite. Primary oxide min-

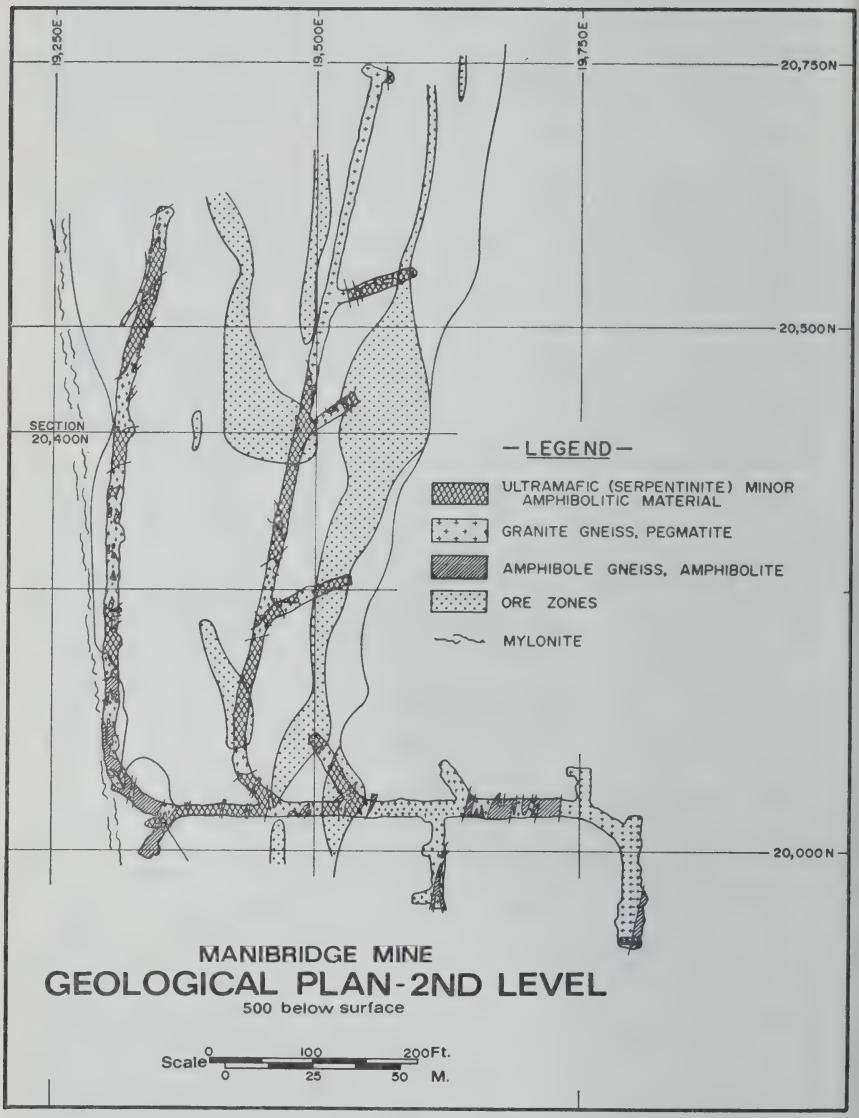

Fig. 20. Geological plan of the 2nd level, Manibridge Mine.

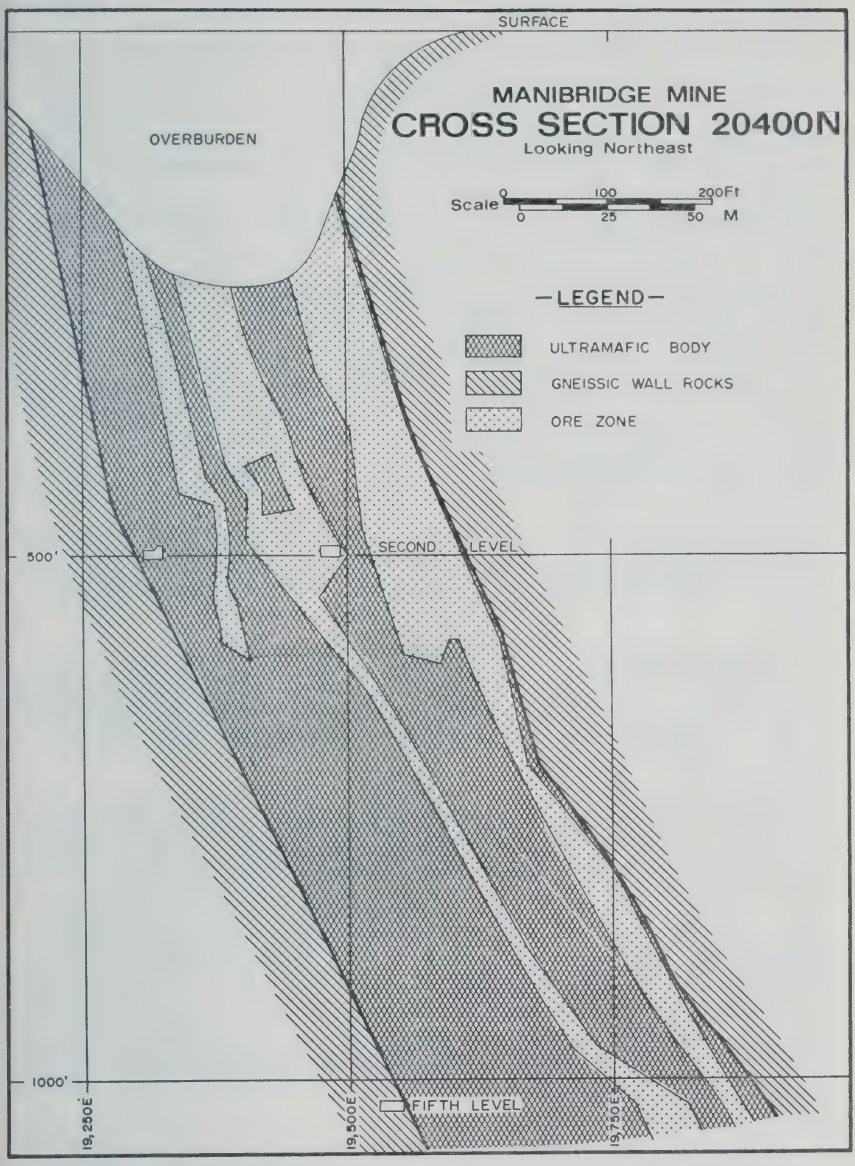

Fig. 21: Cross section 20400, Manibridge Mine, looking northeast.

erals present are magnetite and yellowish-brown to olive-green spinel, both of which occur as small subhedral grains.

Intrusive dykes of pegmatite, ranging in width up to 50 feet (15 m) intersect the ultramafic body. The attitude and continuity of these masses is not yet fully known. They are coarse-grained biotite granite pegmatites consisting of approximately 25 per cent orthoclase, microcline and albite, and about 50 per cent of recrystallized quartz with the typical mortar texture produced by mylonitization. Marginal attrition of the feldspars is noticeable. Coarse biotite, up to 20 per cent, occurs as contorted laths oriented along the major stress direction. Minor minerals present include chlorite, zircon and carbonate. Sulphide minerals pentlandite, pyrite and lesser pyrrhotite and chalcopyrite are associated with the biotite in some instances and may reach 5 per cent by volume. It is probable that these sulphides were mobilized from the surrounding mineralized serpentinite and recrystallized during the shearing movements which fractured and partially mylonitized the pegmatite.

The pegmatite dykes have induced some metasomatic alteration in the adjacent ultramafic rocks resulting in the formation of zones of chlorite, phlogopite, tremolite and anthopyllite.

Serpentinization of the primary silicates is 90 - 100 per cent complete. Olivine has altered to lizardite and magnetite, however pyroxene and amphibole have altered to lizardite with anomalous blue birefringence and minor phlogopite.

Mineralization

A zone of high grade mineralization has a strike length of 275 feet (82 m) with lower grade ore extending the present mineable section to a length of 500 feet (150 m). Ore thickness ranges from minimum mining width up to 100 feet (30 m). At this early stage in mine development it would appear that the high grade zone is composed of two or possibly three overlapping, slightly irregular but distinctly tear drop shaped lenses. Included segments of granite gneiss and to a lesser extent pegmatite appear to have had an important bearing on the location of the high grade zone. Additional lenses of lower grade mineralization are irregularly distributed within the ultramafic body.

Texturally the sulphide mineralization can be classified as disseminated, "net" texture, semi-massive and sulphide breccia, but there is practically a continuous gradation between

them. The quantitatively minor, but high grade breccia ore, occurs as segregations associated with anthophyllite "rims" and related alteration in pegmatite-ultramafic contact areas.

The ore minerals are pentlandite, pyrrhotite, pyrite and chalcopyrite, present in that order of abundance. The pentlandite-pyrrhotite ratio varies from 2:1 to approximately 1:1 and the Ni/Cu ration averages 10. Violarite is a common but variable replacement mineral of pentlandite. Magnetite is a ubiquitous fracture and cleavage-filling mineral in all sulphides.

The available evidence suggests a magmatic origin for the sulphides. They crystallized as an interstitial phase subsequent to the crystallization of olivine, pyroxene, amphibole, primary magnetite and greenish-brown spinel, but prior to the extensive serpentinization of the primary silicates.

PART II

ROAD LOG

Flin Flon Area

Day 1

STOP 1: Flin Flon Mine tour

Hudson Bay Mining and Smelting Co. Ltd.

Day 2

Rock units referred to constitute legend of Figure 4

STOP 1: 4,000 feet (1200 m) north of Flin Flon Mine - North Shaft. Units 1, 2, 3, 4 and 8

At this locality is exposed the fragmental quartz porphyry unit, which to the south is closely associated with the ore zone at Flin Flon mine. The upper contacts with more basic fragmental rocks are well exposed, as are the contacts with a medium sized discordant body of Amisk metadiorite. A small body of Boundary Intrusion, which shows many of the features typical of this group, is entirely within the metadiorite here. A little to the north, the quartz porphyry is overlain by finely banded tuffs. A brief visit will be made to an exposure of tuff containing isolated rounded bombs, which is overlain by a sill of post-Missi feldspar porphyry.

STOP 2: Flin Flon Creek, 2 miles (3.2 km) N. of Flin Flon Mine - North Shaft. Units 1, 6a, 6b.

Here the Missi sandstones are overlain by Amisk rocks along the Club Lake fault, which is probably an early structure associated with thrusting from the south. Both rock units are strongly foliated, and isoclinally interfolded parallel to the fault.

STOP 3: 8500 feet (2550 m) north of Flin Flon Mine - North Shaft. Units 1, 4 and 6a.

Here dykes and sills of Amisk age, and of varying composition, cut basic and intermediate Amisk flow rocks, which are locally pillowed.

STOP 4: 5,000 feet (1500 m) SE of Flin Flon Mine - South Shaft. Units 1 and 4.

This locality illustrates the unconformable contact of the Missi over the Amisk. Amisk metadiorites and pillow lavas immediately below the contact show signs of alteration (spheroidal weathering?). The foliation defined by flattening of the Missi pebbles originated during the main fold episode. This is locally cut by a second, weaker foliation with a more easterly strike.

STOP 5: 6,000 feet (1800 m) SE of the Flin Flon Mine-South Shaft. Units 1 and 2

Amisk pillow lavas, and bedded tuffs with a gentle northwesterly dip are exposed in this outcrop. This is in the east limb of the Burley Lake syncline, one of the few structures in the Amisk which clearly predates the main fold episode.

STOP 6: 5500 feet (1650 m) E. of Flin Flon Mine - South Shaft. Unit 6a

Basal Missi sandstones and conglomerates. Good exposures at this locality show crossbedding, and various other primary structures.

STOP 7: 2.2 miles (3.5 km) NE of Flin Flon Mine - North Shaft. Unit 5. Cliff Lake granodiorite

This rock is often crowded with xenoliths, and the presence of large, blue tinged quartz grains gives it rather a distinctive appearance.

Day 3

STOP 1 — Mileage 0 "A" Mine shaft. Lynn Lake gabbro

Within the shadow of the "A" Mine headframe, the 'discovery outcrop' of the Lynn Lake Mine has been preserved. This mineralized outcrop was uncovered by Austin McVeigh, a prospector for Sherritt Gordon Mines Ltd., in 1941. The sulphide showing lies immediately south of the "A" orebody which was subsequently located by a magnetometer survey and confirmed by diamond drilling. Stringers of sulphide, and disseminated sulphides, are present in the gossan areas of gabbro and amphibolite in the outcrop.

STOP 2 — Mileage 1.0 (1.6 km) Upper "B" open pit stockpile.

Broken rock from the Upper "B" Open Pit illustrates the various types of ore and waste rock. The ore occurs in amphibolite-gabbro and quartz-hornblende diorite as: (a) massive sulphides; (b) disseminated sulphides; and (c) stockworks of sulphide stringers (breccia ore). Most of the sulphide ore occurs in amphibolite.

Sulphides occur in the following relative order of abundance: pyrrhotite, pentlandite, chalcopyrite, pyrite and marcasite. Minor cobalt values are present in the sulphides. The waste rock is amphibolite, gabbro and quartz-hornblende diorite.

STOP 3 — Mileage 1.3 (2.0 km) — Lynn Lake gabbro

Outcrops of gabbro, feldspathic amphibolite and amphibolite, with minor amounts of quartz-hornblende diorite and aphanitic dykes, illustrate the most prevalent rock types in the "A" plug. Banding in the gabbro is evident and to a much lesser extent in the amphibolite. Also significant is the crosscutting relationship of the amphibolite in the gabbro. In places, irregular patches of quartz-hornblende diorite can also be seen. Some of the gabbro appear to grade into diorite. Mine geologists differentiate between these two rock types on the basis of quantity, rather than composition, of the feldspar.

STOP 4. Lynn Lake Mine tour
Sherritt Gordon Mines Ltd.

Lynn Lake to Fox Lake Mine

Day 4

(Mileages measured from Lynn Lake paved road junction on Fox Lake road) Rock units referred to constitute legend of Figure 9.

STOP 1 — Mileage 9.5 S. (15.2 km) 2500 feet (760 m) south
Units 5 and 6

The outcrop shows biotite-hornblende "quartz-eye" granodiorite, in contact with basal Sickle conglomerate. Regionally, this is perhaps the key outcrop in illustrating the break in the stratigraphic succession at the pre-Sickle unconformity. The conglomerate rests with marked unconformity on the post-Wasekwan granodiorite, and contains large pebbles derived from the intrusive. Opalescent blue quartz phenocrysts derived from the granodiorite occur as sand-sized matrix constituents in the conglomerate. The quartz veins in the granodiorite contain good gold prospects, and have been drilled. The drilling company kindly left the entire drill core, which shows both the granodiorite and the conglomerate containing granodiorite clasts.

The granodiorite to the east, intrudes and contains inclusions of volcanic rocks identified as Wasekwan. On this outcrop, the Sickle basal conglomerate rests nonconformably upon the granodiorite. Some of the granodiorite clasts within the conglomerate are cut by quartz veins; others contain amphibolite inclusions. Other types of clasts in the conglomerate include: amphibolite; granite; fine-grained, well-bedded sandstone; quartz; possible tuff; gabbro (?).

This outcrop was described by Milligan (1960) when referring to the unconformable relationships at Pool Lake. However, the drilling was not done until 1966, some 6 years later, and this has confined his original interpretation.

Note the size and diverse shapes of the clasts in the conglomerate. Also note the apparently "open" framework, which is quite deceptive. The matrix is commonly a fine-grained clast which has been warped around the more resistant granitic fragments.

To add weight to the argument that the Sickle conglomerate indeed contains pebbles of near identical composition to the granodiorite, two chemical analyses of the granodiorite and one of a granodiorite clast from the conglomerate are given in Table 3. The analyses are nearly identical. The most

readily apparent compositional difference is the greater FeO content in clasts. The CaO and CO^2 content appears to decrease at the expense of the FeO.

TABLE 3

Chemical Analyses of granodiorite and similar clasts from the Sickle conglomerate at Pool Lake

Wt. %	*(1) Granodiorite*	*(2) Granodiorite*	*(3) Clast*
SiO_2	66.15	65.25	67.3
Al_2O_3	16.2	15.7	16.0
TiO_2	0.34	0.35	0.34
Fe_2O_3	1.55	1.18	1.12
FeO	1.58	1.54	3.42
MnO	0.01	0.01	0.01
MgO	1.10	0.95	1.30
CaO	5.10	5.95	2.87
Na_2O	2.87	3.05	3.80
K_2O	1.37	1.40	1.50
P_2O_5	0.07	0.25	0.04
H_2O	1.09	0.92	1.20
CO_2	2.42	3.57	0.74
TOTAL	99.85%	100.10%	99.65%
Total Fe as Fe_2O_3	3.29	2.87	4.48

STOP 2 — Mileage 11.0 S. (17.6 km) Units 6 and 7

(Approximately 250 feet (75 m) along a cut line on the east side of the McVeigh Station road, 0.4 miles (0.6 km) from the junction with the Lynn Lake-Fox Lake road)

The outcrop at this locality is of basal Sickle conglomerate interbedded with coarse arkose and grit. The contact with Wasekwan rocks is not exposed.

The outcrop is situated on the northern flank of a syncline with an easterly trending axial plane. Higher in the sequence, to the south, the conglomerate persists, and the arkose interbeds become fewer. The conglomerate is eventually overlain by coarse arkose and grit, typical of the Sickle Group.

On this outcrop, the conglomerate is well exposed on the foliation planes and joint planes, both of which are sub-normal to the bedding. The clasts are slightly deformed in the foliation plane, and appear to have been more flattened than elongated. Elongation of approximately 2.5:1 is most common. The foliation has not appreciably deformed bedding planes defined by the arkose.

Note the shallow dip of the bedding, at a high angle to the superimposed cataclastic foliation; the diverse lithologies of the clasts present in the conglomerate; the fine-grained pink "quartz-eye" granite; and the small scour channels at the base of some of the conglomerate beds. The material removed from the channels may have been the source of the arkosic clasts.

STOP 3 — Mileage 23.5 S (37.8 km) Units 4 and 1

The medium-grained gabbro, typical of the basic intrusives of the area, is in contact with the sediments and amphibolitic rocks of unit 1. The contact is poorly exposed on the south side of the road, where the sediments are highly sheared and "baked". The grade of metamorphism is locally higher here than elsewhere. This is attributed to the contact effect of the gabbro. Gabbro alone is exposed on the north side of the road. Amphibole crystals in the gabbro are fractured. The plagioclase shows incipient alteration to carbonate. Sulphides comprise less than 3 per cent of the rock, and appear to be predominantly pyrite.

STOP 4 — Mileage 23.7 S (38.1 km) Unit 1

Regionally, these rocks comprise the lowest sedimentary unit in the Wasekwan Group. They appear to be closely related to the volcanism which marked the beginning of the Wasekwan.

These sediments are remarkably uniform throughout the area. Locally, the unit contains minor coarse clastics. The rocks may represent a fine-grained turbidite or reworked ash sequence, but thermal and dynamic metamorphism has effectively removed all bedding plane features which would aid in interpretation.

The rocks here are remarkable in their low metamorphic grade in spite of their proximity to the gabbro. Note the large epidote "pseudoclasts" in one bed. The epidote segregations are worthy of note in that they appear restricted solely to one bed, or a portion of one bed. They may represent metamorphosed carbonate-rich concretions, or large carbonate-rich clasts. An exact explanation for their origin is not presently known. Elsewhere, clasts similar to these have been variously interpreted as volcanic pisoliths, accretionary lapilli, or having in part a metamorphic origin, as they truncate the fine laminae which define the bedding.

A poorly-developed, second foliation is superimposed over the first, regional, foliation. Local boudinage structures are

contained within the regional foliation. The absence of amphibolites, elsewhere interpreted as having been derived from extrusive volcanics, together with the thin beds of finely-laminated sandstone and siltstone, indicates an extended period of sedimentation, or relative quiescence. The contact with the gabbro (unit 4, Figure 9) is not exposed on this outcrop.

STOP 5 — Mileage 27.0 S (43.2 km) Fox Lake Mine site
Unit 2

North of the Fox Lake Mine, this unit of fine to medium-grained andesite and amphibolite is considered to be part of Wasekwan unit 2. The rock consists mainly of hornblende and feldspar, cut by contorted stringers and small veins of quartz.

STOP 6 — Mileage 27.0 S (43.2 km) Fox Lake Mine site
Unit 7?

An arkosic unit containing pebbles and grains of quartz with some feldspar and hornblende in a siliceous matrix, lies immediately south of the volcanic unit examined at Stop 5. Although tentatively considered to be Sickle arkose of unit 7, there is a great deal of doubt as to its exact age relationship in the sequence.

STOP 7 — Fox Mine tour
Sherritt Gordon Mines Ltd.

Thompson Nickel Belt

Day 5

Thompson to Moak Lake

(Mileage N and S measured from the Burntwood Bridge, Map unit numbers constitute legend of Map 3.)

STOP 1 — Mileage 4.3 N (6.8 km) Map unit 9

This homogeneous, foliated, porphyroblastic granodiorite is inequigranular with excellent dimensional orientation of quartz in lenses. All feldspars exhibit sericite alteration. The plagioclase is bent, subhedral to rarely euhedral and shows sutured to mortar textures, which are due, in part, to secondary recrystallization. Plagioclase 60 per cent; quartz 28 per cent; microcline 7 per cent; muscovite-sericite 5 per cent; biotite, epidote-zoisite, apatite, zircon.

G.S.C. K-Ar date 66-105 (Biotite — 1605 $\pm$ 50 m.y. Muscovite — 1615 $\pm$ 50 m.y.) was obtained from this stock. These dates can be compared with G.S.C. 66-100, 101, 102 and

103 (1.515 - 1.630 m.y.) from the Thompson Mine. Further, these dates should be compared with previously determined dates for rock of similar occurrence and appearance in the area, specifically G.S.C. 65-101, a pegmatite from the Ospwagan granite which cuts metasediments typical of the Thompson belt. Muscovite from this pegmatite gave an age of 2035 ± 70 m.y. From an island in Setting Lake, biotite from a stock of quartz monzonite (G.S.C. 63-105) gave an age of 1785 ± 60 m.y. G.S.C. 64-82, a biotite-hornblende-quartz monzonite from north of Resting Lake may be added to this series. The hornblende in this rock has been dated at 1690 ± 170 m.y.

All of these various bodies of acidic composition, which have been dated, are considered to be intrusions. They occur over a distance of 70 miles (112 km) along the strike of the Thompson belt. The dates may give an indication of the minimum length of time during which this zone was undergoing rather intense orogeny, or at least, metamorphism i.e. from early Proterozoic until middle Proterozoic. (Wanless et al., 1968, pages 89-90.

STOP 2 — Mileage 6.8 N (10.8 km) Map unit 11.

The mineralized outcrop of serpentinized peridotite on the southwest shore of Mystery Lake is the only exposure of mineralized ultramafic rock in the Thompson nickel belt. Sulphide minerals are pyrrhotite and pentlandite with minor amounts of chalcopyrite and violarite. The sulphides enclose small grains of reddish-brown spinel and encircle rounded pseudomorphs of serpentine after olivine.

STOP 3 — Mileage 15.9 N (25.4 km) Map unit 5.

Highly contorted banded iron formation, containing iron-rich amphibole (probably grunerite), quartz, magnetite and garnet. This highly magnetic unit forms part of the metasedimentary sequence outcropping between Moak Lake and Ospwagan Lake.

STOP 4 — Mileage 17.5 N (28 km) Map unit 5 or 7

It is uncertain whether this cataclastic gneiss, presumably derived from a gneiss of granodioritic composition, should be correlated with the metasediments of unit 5 or the gneissic rocks of unit 7.

STOP 5 — Mileage 17.7 N (28.3 km) Map unit 5 or 7

Where cataclastic deformation has proceeded to a degree where the nature of the original rock type is uncertain, the

term mylonite is preferentially used in the description. A portion of this small outcrop is ultramylonite, and has the appearance of a thinly bedded chert. A steep lineation is evident on foliation planes.

STOP 6 — Mileage 18.2 N (29.1 km) Map unit 7

This exposure of cataclastic gneiss, principally granodioritic in composition, is of interest for the interbedded mafic layers, minor faults and folds, and cross-cutting, post-cataclastic pegmatite. Two sets of lineations are apparent.

STOP 7 — Mileage 20.5 N (32.8 km) Map units 5, 7 and 11

On the dumps at the Moak Mine, various phases of serpentinite and mineralized serpentinite from the underground workings may be examined. Sulphide minerals are chiefly pyrrhotite and pentlandite, with minor amounts of chalcopyrite and violarite. Magnetite-filled fractures are common in the serpentinite. Waste dumps are composed of mylonites and various mylonitized gneissic rocks which comprise the wallrocks to the ultramafic body. A description of the geology of the Moak mine is included in the text.

Day 6

Thompson Mine to Pipe Mine

STOP 8 — Mileage 1.9 S (3 km) Thompson Mine tour
International Nickel Company of Canada Ltd.

STOP 9 — Mileage 1.3 S (2 km) Map unit 7

The outcrop at the Highland Towers immediately south of Thompson, is a mylonitized biotitic gneiss on the southwestern continuation of the Mystery Lake-Burntwood River lineament. This cataclastic zone is several hundred feet thick and dips steeply to the southeast. Under the road to the northwest, the faulting is more intense with a thoroughly broken fault zone which has been intersected by exploration diamond drilling. The Thompson Mine lies southeast of this fault.

Complex folding and porphyroclasts or micro-augen are a feature of the outcrop. The steeply plunging folds appear to have formed in the final stages of mylonitization. Similar structures are commonly found on a micro-scale in cataclastic rocks at Moak Lake, Mystery Lake and along the continuation of the same fault system to the south at Setting Lake. At all these localities the micro-folds are invariably steeply plunging and suggest strike-slip movement on the fault system, at least in the final stages of the movement.

STOP 10 — Mileage 19.6 S (31.4 km) Map unit 7

At the south end of the peninsula overlooking the west side of Paint Lake, the outcrops of layered paragneiss contain minor hypersthene. The eastern part of this outcrop is fairly typical of the hypersthene-bearing phases of the eastern margin of this rock unit, but the relationship of this unit to the pyroxene granulites of map unit 13 is unknown. Abundant pegmatite stringers parallel the gneissic foliation.

STOP 11 — Mileage 22.7 S (36.3 km) Pipe Mine open-pit International Nickel Company of Canada Ltd.

Day 7

Pipe Mine to Manibridge Mine

STOP 12 — Mileage 26.6 S (42.5 km) Map units 7, 8 and 11

A small lens-shaped body of metamorphosed ultramafic rock (metaperidotite) at this locality is enclosed in biotite granite gneiss and amphibolite. The ultramafic rock consists of 65 to 70 per cent colourless, equigranular mosaic of amphibole and 25 to 30 per cent orthopyroxene. The latter occurs as inequigranular, coarse poikilitic grains containing inclusions of amphibole. Approximately 5 per cent clinochlore, some with inclusions of amphibole, traces of brownish-green spinel, pale coloured biotite and minor sulphides and oxides complete the assemblage. Note the folds in the granite gneiss which is cut by later granite pegmatite.

STOP 13 — Mileage 42.8 S (68.5 km) Map unit 8

This outcrop of black amphibolite forms part of a steeply dipping band of mafic rocks, about one-half mile (0.8 km) wide, that extends northeasterly for 16 miles (25 km) from Soab Lake to Paint Lake. The rock is well foliated and exhibits a pronounced lineation from the alignment of amphibole crystals. Layering is evident, with variations from thin to thick layers and differences in grain size between layers.

STOP 14 — Mileage 45.6 S (73 km) Map unit 7

From the picnic area at this locality there is a scenic view of Pisew Falls which cascade 43 feet (12.9 m) into the Grass River. The rocks which underlie the falls are amphibolite and garnetiferous gneiss. The river gorge below the falls has been eroded from a friable fault zone, trending northeasterly, which forms part of the nickel belt fault system. Layered granodioritic gneiss or migmatite underlies the observation area on the west side of the fault.

STOP 15 — Mileage 51.1 S (81.7 km) Map unit 7

Outcrops on the shore of Setting Lake above Sasagiu Rapids, alongside the rapids, and below the rapids on Brostrom Lake are composed of layered granodioritic gneiss containing variable amounts of hornblende, biotite and introduced granitic material. Refolded folds with shallow plunges (domes and saddles) are evident in the outcrops along Setting Lake. This outcrop reflects the regional structure, which consists of two major dome structures in a north-south line and related basin or synclinal structures in an east-west line, occupied by Setting Lake and Brostrom Lake respectively. The Sasagiu Rapids have resulted from the river flowing through a saddle between the two domal features (Figure 22).

STOP 16 — Mileage 67.7 S (108.3 km) Map unit 7

In the village of Wabowden, the outcrop of highly contorted, thinly layered, hornblende granodioritic or quartz dioritic gneiss or migmatite is typical. This convoluted structure is characteristic of the gneisses and migmatites that wrap around the northeast end of the body of hornblende quartz monzonite (map unit 10), which lies immediately to the southwest.

Shaft sinking and underground exploration programs are being undertaken by Bowden Lake Nickel Mines Ltd., on two low grade nickel deposits in the Wabowden area. Bowden Lake Nickel Mines Ltd. is owned 60 per cent by Falconbridge Nickel Mines Ltd., 34 per cent by Consolidated Marbenor and 6 per cent by Rio Tinto Canadian Exploration. Heavy overburden has hindered surface exploration and underground drilling is required to confirm a possible 30,000,000 tons grading about 0.78% nickel under Bucko Lake, 3 miles (4.8 km) south of Wabowden, and to provide detailed information on a lower grade zone with dimensions of 6,500 x 1200 feet (1950 x 360 m) under Bowden Lake. The Bowden Lake deposit could have a potential of 80,000,000 tons to a depth of 1,000 feet (300 m) and a grade of about 0.6% nickel.

STOP 17 — Mileage 67.7 S (108.3 km) Map unit 7

On the east shore of Setting Lake, the exposures represent highly pegmatized or granitized variations of the gneissic rocks at Wabowden, Sasagiu Rapids and Pisew Falls, but are still considered the same map-unit. The mafic sills containing euhedral to ovoid shaped feldspars have fine-grained margins. These sills occur only at this locality.

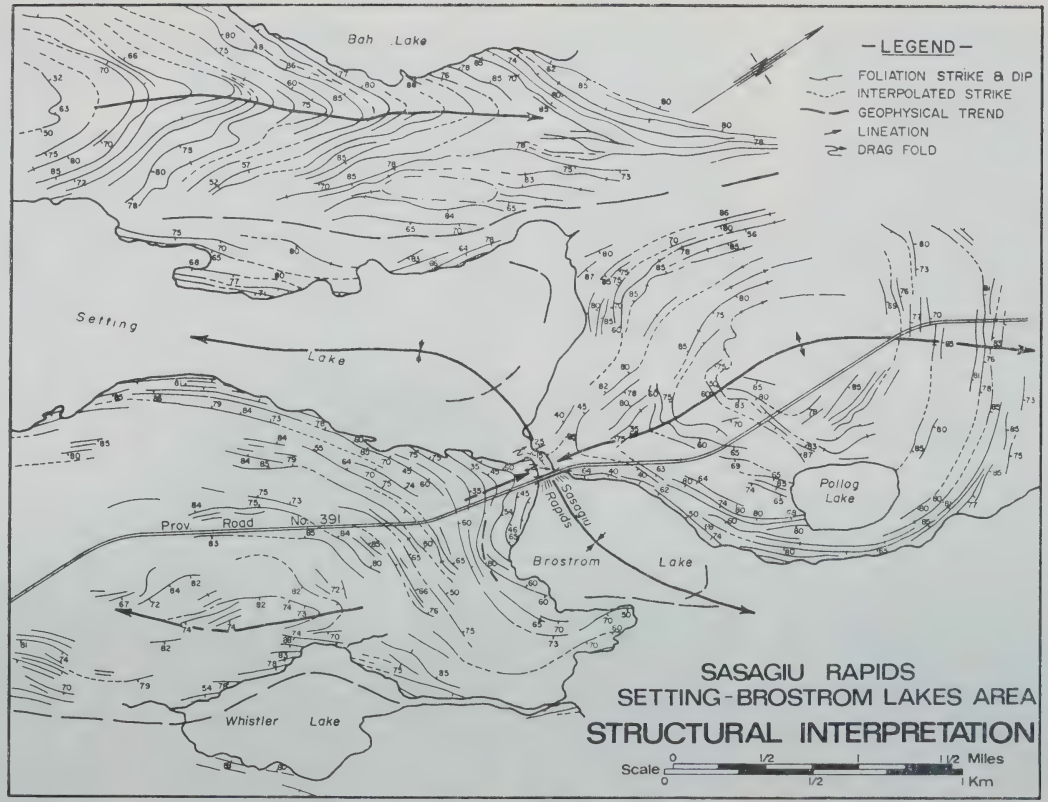

Fig. 22: Structural interpretation of the Setting-Brostrom Lakes area atSasagiu Rapids.

Along the eastern side of Setting Lake at varying distances from the shore, a major mylonite zone has associated lenticular masses of serpentinized peridotite. This major fault zone is one of a number extending the entire length of Setting Lake and is considered to represent a principal branch of the nickel belt fault system.

STOP 18 — Mileage 73.2 (117 km) Map unit 10

A gneissic, syntectonic or pretectonic intrusion of hornblende quartz monzonite is exposed at a number of localities in this general low-lying area. An extensive stockwork of pink granite and pegmatite stringers permeates the monzonite and both hematite and epidote alteration has developed in minor shear zones. Some rare inclusions of plagioclase amphibolite are evident. K-Ar age determination (G.S.C. 64-82) on hornblende from this intrusion is 1690 ± 170 m.y. (Wanless, et al., 1966, p. 56.)

STOP 20 — Mileage 83.7 (134 km) Manibridge Mine tour Falconbridge Nickel Mines Ltd.

Day 8

The Thompson Plant

The Thompson mill of The International Nickel Company of Canada, Limited, began operating in 1960, treating a sulphide ore having a copper-to-nickel ratio of approximately 1 to 15.

Ore is crushed in an underground jaw crusher and also at an outside unloading and crushing area. The crusher jaws are set at 6 inches (15 cm), and the crushed ore is hoisted directly directly into the mill's coarse ore bins. It is further crushed to 0.5 inch (1.27 cm) size in cone crushers, and ground to 65 mesh in a rod and ball mill grinding circuit. The ground ore is then subjected to froth flotation, producing a nickel concentrate, a copper concentrate and sand fill. The nickel concentrate is pumped to the smelter. The copper concentrate is dewatered, dried and shipped to Copper Cliff, Ontario. Sand recovered from the flotation tailings is used as fill material underground, and the slime fraction is pumped to the disposal area.

The nickel concentrate pulp is thickened, filtered, mixed with sand flux and fed to fluid bed roasters.

Air injection into the roasters oxidizes a portion of the sulphur and iron in the feed. The autogenous heat produced

in this reaction is used to produce the hot calcine furnace charge. The resulting hot calcine and heated flux is recovered by cyclones in the gas stream and through automatic dump valves in the roaster bed. The mixture drops by gravity into an insulated drag conveyor system that feeds the electric furnaces. The partially desulphurized roaster product is fed to the electric furnaces along each side wall through fettling pipes in the roof. In the furnaces, it melts, mixes with recycled converter slag, and separates into matte and slag phases. The matte is tapped through the front end wall into ladles and transferred to the converters. The slag is tapped through the back end wall into the granulating system and pumped to the disposal area.

In the converters, the iron is removed from the furnace matte and a high-grade nickel sulphide matte (Bessemer matte) is produced. Molten nickel sulphide matte is received from the smelter converters and is cast directly into anodes. This results in a great improvement over conventional metal anode processing. The anodes are corroded electrolytically in the nickel-plating cells, using pure nickel starting sheets as cathodes. The difference in current efficiency between cathode and anode produces excess acid in the anolyte. Therefore, ground anode scrap is leached for nickel replenishment, which is used to neutralize the excess acid formed at the plating cell anodes and replace it with nickel.

Anolyte from the plating cells is treated for the removal of impurities such as iron, arsenic, cobalt and copper, and is returned to the cells as a purified solution from which the nickel is plated. Other plant products, in addition to electrolytic nickel cathodes, are cobalt oxide, and sulphur and precious metals concentrate derived from the treatment of the anode slime.

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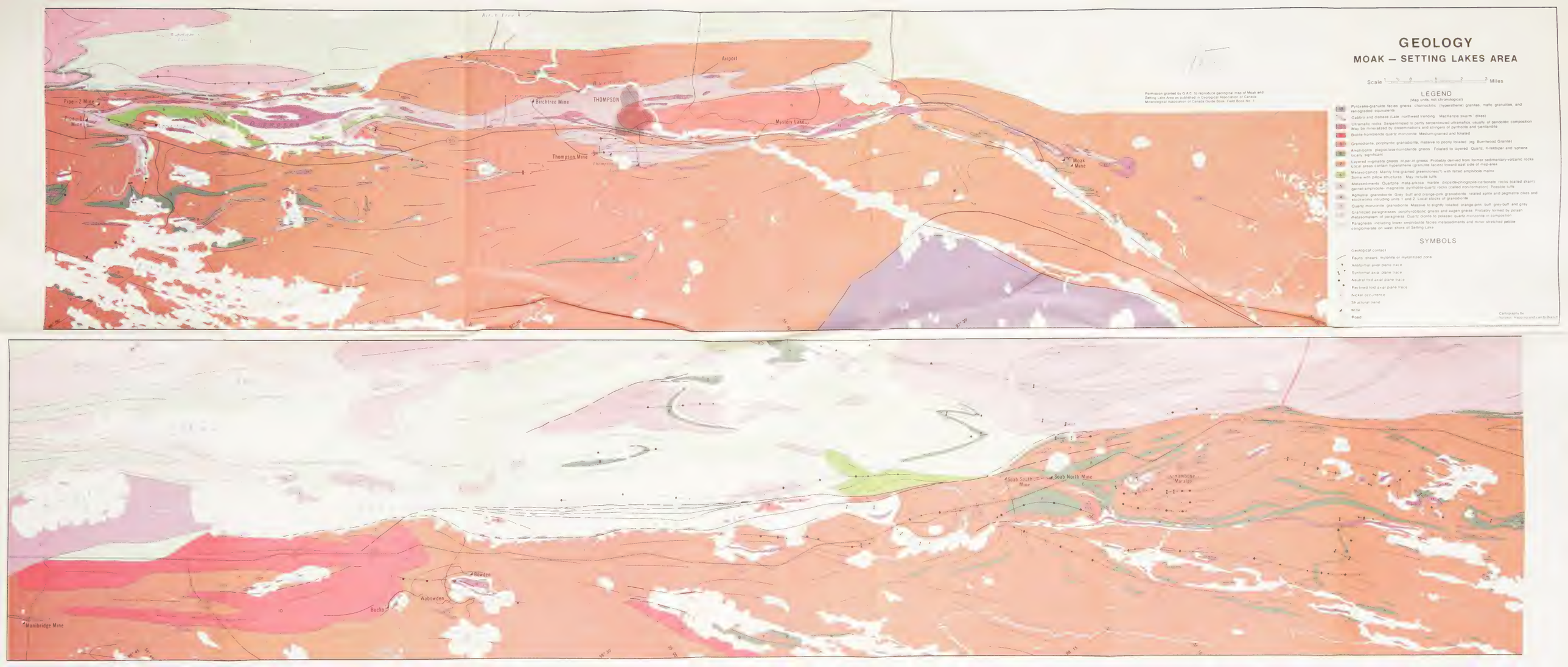
GEOLOGY
MOAK — SETTING LAKES AREA
Scale 1 0 1 2 3 Miles
Permission granted by G.A.C. to reproduce geological map of Moak and Setting Lake Area as published in Geological Association of Canada Mineralogical Association of Canada Guide Book - Field Book No. 1
LEGEND
(Map units, not chronological)
Pyroxene-granulite facies gneiss: charnockitic (hypersthene) granites, mafic granulites, and retrograded equivalents
Gabbro and diabase (Late northwest trending Mackenzie swarm dikes)
Ultramafic rocks. Serpentinized to partly serpentinized ultramafics, usually of peridotitic composition May be mineralized by dissemination and stringers of pyrrhotite and pentlandite
Biotite-hornblende quartz monzonite Medium-grained and foliated
Granodiorite, porphyritic granodiorite, massive to poorly foliated (eg. Burntwood Granite)
Amphibolite plagioclase-hornblende gneiss. Foliated to layered. Quartz, K-feldspar and sphene locally significant
Layered migmatite gneiss in part of gneiss. Probably derived from former sedimentary-volcanic rocks Local areas contain hypersthene (granulite facies) toward east side of map-area
Metavolcanics Mainly fine-grained greenstones(?) with felted amphibole matrix Some with pillow structures. May include tuffs
Metasediments Quartzite, meta-arkose, marble, diopside-phlogopite-carbonate rocks (called skarn) garnet-amphibole- magnetite pyrrhotite-quartz rocks (called iron-formation) Possible tuffs
Agmatite granodiorite Grey, buff and orange-pink granodiorite, related aplite and pegmatite dikes and stockworks intruding units 1 and 2. Local stocks of granodiorite
Quartz monzonite granodiorite Massive to slightly foliated, orange-pink, buff, grey-buff and grey
Granitized paragneisses porphyroblastic gneiss and augen gneiss Probably formed by potash metasomatism of paragneiss. Quartz diorite to potassic quartz monzonite in composition
Paragneiss including lower amphibolite facies metasediments and minor stretched pebble conglomerate on west shore of Setting Lake
SYMBOLS
Geological contact
Faults, shears, mylonite or mylonitized zone
Antiformal axial plane trace
Synformal axial plane trace
Neutral fold axial plane trace
Reclined fold axial plane trace
Nickel occurrence
Structural trend
Mine
Road
Cartography by Surveys, Mapping and Lands Branch
Birch Tree Lake
Airport
Pipe – 2 Mine
Pipe – 1 / 3 Mine
Birchtree Mine
THOMPSON
Mystery Lake
Thompson Mine
Moak Mine
Seab South Mine
Seab North Mine
Bowden
Wabowden
Bucko
Manibridge Mine

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GEOLOGY

LYNN LAKE—SOUTHERN INDIAN LAKE AREA

Scale 5 0 5 10 15 20 Miles

PRECAMBRIAN

POST-SICKLE INTRUSIVE ROCKS

12 Diabase; minor lamprophyre.

11 Quartz monzonite; minor pegmatite, aplite, microcline granite, syenite, alaskite.

10 Granodiorite; minor quartz monzonite.

9 Diorite, quartz diorite; minor biotite-hornblende tonalite and hornblende granodiorite.

8 Ultramafic rocks; hornblendite; gabbro; pyroxene diorite; ortho-amphibolite. Includes Black Trout diorite.

GNEISSES OF UNCERTAIN AFFINITY

O Opachuanau gneisses: migmatite; hornblende-biotite gneiss; amphibole-plagioclase gneiss; amphibolite. (derived from Sickle and or Wasekwan Group rocks).

K Kissseynew-type gneisses: (derived from Sickle and Wasekwan Group rocks)

SICKLE GROUP

7 Arkosic gneiss; biotite - muscovite - quartz schist, microcline ± plagioclase ± magnetite paragneiss, metatexite and diatexite

6 Arkose, feldspathic greywacke; minor siltstone, chert, quartzite, pebble beds and calcareous sediments

5 Conglomerate with minor interbedded arkose.

4a Amphibolite (locally with calc-silicate-carbonate layers); in part interlayered with biotite-plagioclase gneiss. (Age and origin uncertain)

PRE-SICKLE INTRUSIVE ROCKS

4 Quartz diorite; diorite; minor granodiorite

3 Hornblende gabbro; norite; hornblendite; pyroxenite; minor ultramafic amphibolite

WASEKWAN GROUP

2(b) Fragmental volcanic rocks: acid tuff; agglomerate; interbedded metasediments and massive flows; derived amphibolite

2(a) Metavolcanic flows: basalt; andesite; minor dacite, rhyolite; interbedded metasediments, amphibolite.

1(c) Plagioclase ± microcline diatexite (Derived from 1(a))

1(b) Pelitic and semi-pelitic paragneiss; plagioclase ± microcline metatexite (Derived from 1(a)).

1(a) Fine-grained feldspathic greywacke, volcanic wacke, minor siltstone, quartzite, conglomerate and calc-silicate rocks.

Cartography by
Surveys, Mapping and Lands Branch

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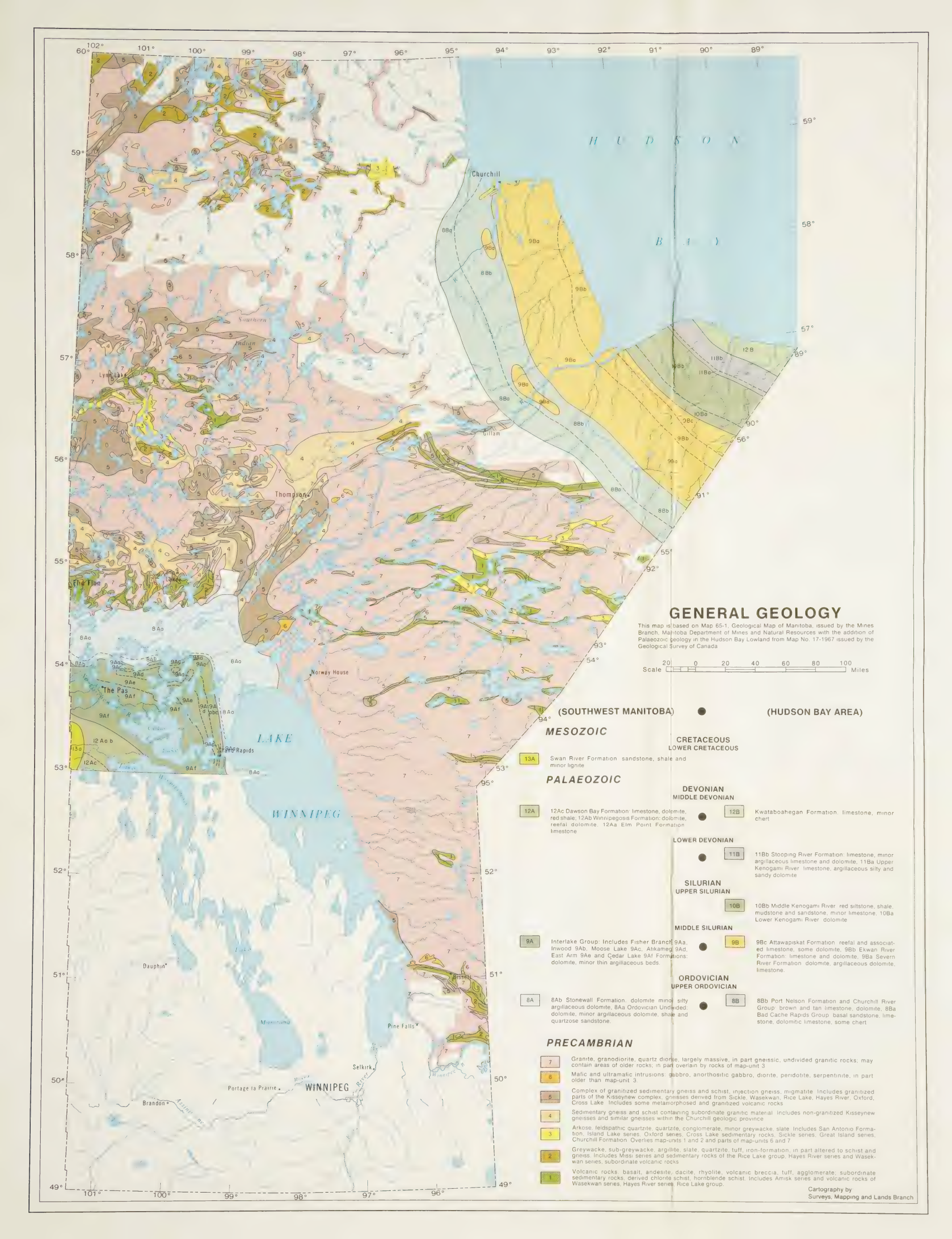

GENERAL GEOLOGY

This map is based on Map 65-1, Geological Map of Manitoba, issued by the Mines Branch, Manitoba Department of Mines and Natural Resources with the addition of Palaeozoic geology in the Hudson Bay Lowland from Map No. 17-1967 issued by the Geological Survey of Canada

Scale 20 0 20 40 60 80 100 Miles

(SOUTHWEST MANITOBA) ● (HUDSON BAY AREA)

MESOZOIC

CRETACEOUS
LOWER CRETACEOUS

13A — Swan River Formation: sandstone, shale and minor lignite

PALAEOZOIC

DEVONIAN
MIDDLE DEVONIAN

12A — 12Ac Dawson Bay Formation: limestone, dolomite, red shale; 12Ab Winnipegosis Formation: dolomite, reefal dolomite. 12Aa Elm Point Formation: limestone

12B — Kwataboahegan Formation: limestone, minor chert

LOWER DEVONIAN

11B — 11Bb Stooping River Formation: limestone, minor argillaceous limestone and dolomite. 11Ba Upper Kenogami River: limestone, argillaceous silty and sandy dolomite

SILURIAN
UPPER SILURIAN

10B — 10Bb Middle Kenogami River: red siltstone, shale, mudstone and sandstone, minor limestone. 10Ba Lower Kenogami River: dolomite

MIDDLE SILURIAN

9A — Interlake Group: Includes Fisher Branch: 9Aa, Inwood 9Ab, Moose Lake 9Ac, Atikameg 9Ad, East Arm 9Ae and Cedar Lake 9Af Formations: dolomite, minor thin argillaceous beds.

9B — 9Bc Attawapiskat Formation: reefal and associated limestone, some dolomite. 9Bb Ekwan River Formation: limestone and dolomite. 9Ba Severn River Formation: dolomite, argillaceous dolomite, limestone.

ORDOVICIAN
UPPER ORDOVICIAN

8A — 8Ab Stonewall Formation: dolomite minor silty argillaceous dolomite. 8Aa Ordovician Undivided: dolomite, minor argillaceous dolomite, shale and quartzose sandstone.

8B — 8Bb Port Nelson Formation and Churchill River Group: brown and tan limestone, dolomite. 8Ba Bad Cache Rapids Group: basal sandstone, limestone, dolomitic limestone, some chert

PRECAMBRIAN

7 — Granite, granodiorite, quartz diorite, largely massive, in part gneissic, undivided granitic rocks; may contain areas of older rocks; in part overlain by rocks of map-unit 3

6 — Mafic and ultramafic intrusions: gabbro, anorthositic gabbro, diorite, peridotite, serpentinite, in part older than map-unit 3.

5 — Complex of granitized sedimentary gneiss and schist, injection gneiss, migmatite. Includes granitized parts of the Kisseynew complex, gneisses derived from Sickle, Wasekwan, Rice Lake, Hayes River, Oxford, Cross Lake. Includes some metamorphosed and granitized volcanic rocks

4 — Sedimentary gneiss and schist containing subordinate granitic material. Includes non-granitized Kisseynew gneisses and similar gneisses within the Churchill geologic province

3 — Arkose, feldspathic quartzite, quartzite, conglomerate, minor greywacke, slate. Includes San Antonio Formation, Island Lake series, Oxford series, Cross Lake sedimentary rocks, Sickle series, Great Island series, Churchill Formation. Overlies map-units 1 and 2 and parts of map-units 6 and 7

2 — Greywacke, sub-greywacke, argillite, slate, quartzite, tuff, iron-formation, in part altered to schist and gneiss. Includes Missi series and sedimentary rocks of the Rice Lake group, Hayes River series and Wasekwan series, subordinate volcanic rocks

1 — Volcanic rocks, basalt, andesite, dacite, rhyolite, volcanic breccia, tuff, agglomerate; subordinate sedimentary rocks, derived chlorite schist, hornblende schist. Includes Amisk series and volcanic rocks of Wasekwan series, Hayes River series, Rice Lake group.

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Surveys, Mapping and Lands Branch

GENERAL GEOLOGY

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Scale 20 0 20 40 60 80 100 Miles

(SOUTHWEST MANITOBA) ● (HUDSON BAY AREA)

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LOWER CRETACEOUS

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PALAEOZOIC

DEVONIAN
MIDDLE DEVONIAN

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12B — Kwataboahegan Formation: limestone, minor chert

LOWER DEVONIAN

11B — 11Bb Stooping River Formation: limestone, minor argillaceous limestone and dolomite, 11Ba Upper Kenogami River: limestone, argillaceous silty and sandy dolomite

SILURIAN
UPPER SILURIAN

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UPPER ORDOVICIAN

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1 — Volcanic rocks: basalt, andesite, dacite, rhyolite; volcanic breccia, tuff, agglomerate, subordinate sedimentary rocks, derived chlorite schist, hornblende schist. Includes Amisk series and volcanic rocks of Wasekwan series, Hayes River series, Rice Lake group

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GEOLOGY

SNOW LAKE FLIN FLON SHERRIDON AREA

Scale 2 0 2 4 6 8 Miles

RECENT AND PLEISTOCENE sand, silt, clay.

Great Unconformity

PALEOZOIC Argillaceous limestone, calcareous sandstone.

Great Unconformity

PRECAMBRIAN

KISSEYNEW SEDIMENTARY GNEISS BELT

POST-SHERRIDON INTRUSIVE GROUP

K6 Pyroxenite, gabbro.

K5 Pink granodiorite gneiss. In part represents granitized portions of unit K3.

K4 White, grey, gneissic quartz monzonite and granodiorite, derived in part from unit K1.

Intrusive Contact

SHERRIDON GROUP

K3 Siliceous paragneisses derived from monotonous sequence of arkosic to quartzitic sedimentary rocks, possibly equivalent to unit A6. Includes undifferentiated material transitional into unit K5.

Disconformity

NOKOMIS GROUP

K2 Hornblende—plagioclase gneisses.

K1 Intermediate garnetiferous paragneisses derived from a repetitious sequence of greywacke and argillite, possibly equivalent to unit A3. Includes migmatitic and granitoid phases.

BASEMENT GROUP

K0 Variable sequence of metasomatized granitoid paragneisses.

FLIN FLON—SNOWLAKE GREENSTONE BELT

POST-MISSI INTRUSIVE GROUP

A8 Intrusive phases of A7. Variable composition.

A7 Granodiorite and quartz diorite, generally gneissic. Large portions represent granitized sedimentary rocks of unknown age.

Intrusive Contact

MISSI GROUP

A6 Arkose, greywacke, quartzite. Basal conglomerate common.

Unconformity

POST-AMISK INTRUSIVE GROUP

A5 Gabbro and diorite often with ultrabasic phases. Commonly differentiated. Includes rocks of several ages and diverse origins.

A4 Granitic rocks with characteristic blue quartz phenocrysts.

Intrusive Contact

AMISK GROUP

A3 Argillite, greywacke, tuff. Turbidites common in the eastern region.

A2 Rhyolite, dacite, quartz porphyry. Includes acidic crystal tuff and siliceous, carbonate—rich tuff.

A1 (b) Basic to intermediate fragmental volcanic rocks, interbedded with unit A1a.
(a) Predominantly pillowed basalt and andesite. Includes many small related intrusions.

COPPER-ZINC SULPHIDE DEPOSITS

VOLCANIC BELT	TRANSITIONAL	SEDIMENTARY GNEISS BELT
1. FLIN FLON	14. JOANNIE LAKE	18. OSBORNE LAKE
2. MANDY	15. ANDERSON LAKE	19. SHERRIDON
3. SCHIST LAKE	16. STALL LAKE	20. JUNGLE
4. CUPRUS	17. STALL LAKE MINES LTD.	21. BOB LAKE
5. WHITE LAKE		22. WIM LAKE
6. PINE BAY		
7. NORTH STAR		
8. LUCILLE LAKE		
9. GRASS RIVER		
10. DICKSTONE		
11. BOMBER		
12. CHISEL LAKE		
13. GHOST LAKE		
23. COPPER-MAN		
24. POT LAKE		
25. CENTENNIAL		
26. REED LAKE		
27. RAIL LAKE		

N

55° 30'
55° 15'
55° 00'
54° 45'
54° 30'
101° 45'
101° 30'
101° 15'
101° 00'
100° 45'
100° 30'
100° 15'
100° 00'
99° 45'
99° 30'

Sherridon
Flin Flon
Snow Lake
Kisseynew Lake
Athapapuskow Lake
Simonhouse Lake
File Lake
Elbow Lake
Reed Lake
Wekusko Lake
Wimapedo Lake
Batty Lake
Undifferentiated Metasediments

SYMBOLS

- Geological Contact
- Fault
- Northern Boundary of Volcanic Belt
- Northern Boundary of Palaeozoic Rocks
- Mined Out Deposit
- Producing Deposit
- Developing Deposit
- Underground Exploration
- Mineral Deposit

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